La

EN

A

TREATISE

ON

ENGINEERING CONSTRUCTION

EMBRACING

DISCUSSIONS OF THE PRINCIPLES INVOLVED, AND
DESCRIPTIONS OF THE MATERIAL EMPLOYED,

IN

TUNNELLING, BRIDGING, CANAL AND ROAD
BUILDING, ETC., ETC.

BY

J. E. SHIELDS, C. E.,

WITH FORTY-FOUR ILLUSTRATIONS.

NEW YORK:
D. VAN NOSTRAND, PUBLISHER,
23 MURRAY AND 27 WARREN STS.

1877.

PREFACE.

The Author of this work desires to direct attention to the true principles of Construction, as declared by the highest authorities, and tested by his own experience in a professional practice of many years.

All theories bearing upon any subject treated of in this work lacking the confirmation of practical test have been excluded.

J. E. SHIELDS.

CONTENTS.

FOUNDATIONS.

MASONRY.

FOUNDATIONS.

The principles to be kept in view in the treatment of all cases where the natural soil is at all of a doubtful character, are: *First*,—To distribute the weight of the structure over a large area of bearing surface. *Second*,—To prevent the lateral escape of the supporting material.

DIVISION A.

Foundations in situations where water offers no impediment to the execution of the works.

CLASS I.—Foundations formed in situations where the natural soil is sufficiently firm to bear the weight of the superstructure.

Case 1.—*Bearing stratum not liable to be affected by exposure to air or water; such as solid rock, indurated gravel, &c.*

In founding upon a natural bottom of this kind, the only precaution necessary is to level the foundation pits, so that the masonry may start from a horizontal bed. Should any vacuities or irregularities occur in the firm ground, it will be found better to fill them up with concrete, which, once set, is nearly incompressible under anything short of a crushing force, rather than to bring up masonry for that purpose, seeing that the compression of the mortar-joints is sure to cause some irregular settlement. If it is unavoidably necessary

that some parts of the foundation shall start from a lower level than others, care must be taken to keep the mortar-joints as close as possible, or to execute the lower portions of the work in cement, or some hard-setting mortar, otherwise it will be very difficult to keep the courses level in the superstructure, the work settling most at those points where the greatest number of mortar-joints occur. Strong gravel may be considered as one of the best soils to build upon, as it is almost incompressible, and is not affected by exposure to the atmosphere, and is easily levelled.* Sand is also almost incompressible and forms an excellent foundation so long as it can be kept from escaping; but as it has no cohesion, and acts like a fluid when exposed to running water, it must be looked upon with suspicion and treated with caution. A bottom of solid rock, although at first sight appearing to offer many advantages to the builder, is not in practice found to be a desideratum. The labor of forming a level bed is generally considerable,† and unless the strata be nearly

* The superiority of gravel over clay, as a bearing stratum, is shown in the case of the bridge over the Grand Junction Canal, England. The rails were laid upon girders resting upon bed plates, with piles under each end, part of these piles were driven into dry gravel, and a few into clay. It was found that when the engines passed over the former, no visible effect was produced, but with the latter there was an evident sinking. The result of such experience induced the belief that in clay or wet soils it was not advisable to trust to a greater weight than 12 tons upon each pile, but in gravel there was scarcely any limit to their vertical bearing strength.

† Account of the Skerryvore Lighthouse, England. "After the success which has attended the efforts of the French Engineers employed on the harbor works of Algiers, in forming béton foundations on the most rugged rocks and exposed to heavy seas, it may be fairly questioned whether in cases similar to that of the Skerryvore, a foundation of béton, dovetailed as it were, into the natural cavities of the rock, would not prove as efficient against the force of the waves as one formed by cutting away the rock to form a sunken bed, as done at Skerry. It affords an example of the trouble and expense of preparing a level bed in hard rock. In the construction of the Eddystone Lighthouse, the rock on which it stands was cut into steps, and each course of masonry was dovetailed into the upright face of the steps. At the Skerryvore, the base of the structure was brought to a uniform level and sunk below the adjacent surface of the rock. The following is an extract from an account of the work by the engineer in

level it commonly happens in the area of a large building that some portions will rest upon the rock, and others upon some adjacent structure, as clay or gravel, and the irregularity of settlement thus caused is most troublesome to deal with.‡ Beds of rock with partings of clay between them

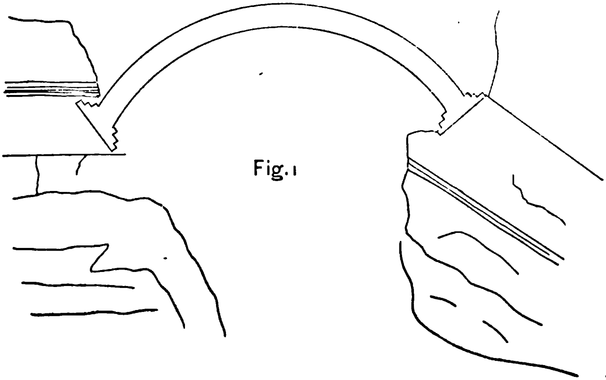
---

charge. "After a careful survey of the rock, and having fully weighed all the risks of injuring the foundation, I determined at once to enter upon a horizontal cut, so as to lay bare a level floor, of extent sufficient to contain the foundation-pit for the tower. The very rugged and uneven form of the rock made this an almost necessary precaution, in order to prevent any misconception as to its real state, for it was traversed by numerous veins and bands, inclined at various angles, on the position and extent of which the stability of the foundation in no small degree depended. That operation occupied 30 men for 102 days, and required the firing of 241 shots, chiefly horizontal, while the quantity of material removed did not exceed 2,000 tons. When the floor had been roughly levelled I again carefully surveyed the rocks, with a view of fixing precisely the site of the foundation-pit, and of taking advantage of its form and structure to adopt the largest diameter for the tower of which the rock would admit. After much deliberation and repeated examinations of all the veins and fissures, I was enabled to mark out a foundation-pit of 42 feet in diametor on one level throughout. The outlines of the circular foundation-pit, 42 feet in diameter, having been traced with a trainer on the rock, numerous jumper-holes were bored in various places, having their bottoms all terminating in one level plane, so as to serve as guides for the depth to which the basin was to be excavated. The depth did not exceed 15 inches below the average level already laid bare by the cutting of the rough horizontal floor, which has just been described. Another source of labor was the dressing of the vertical edges of the basin, as that implied cutting a square check 15 inches deep and 130 feet long in the hardest gneiss rock. The plan employed was to bore all around the periphery of the circle 15-8 inch vertical jumper-holes, 6 inches apart, to the required depth, and to cut out the stone between them. The surface thus left was afterwards carefully dressed, so as to admit vertical and horizontal moulds, representing truly the form of the masonry which the check was intended to receive. The experience attending that operation gave me reason for congratulation on having adopted a foundation on one level throughout, instead of cutting the rock into several terraces, at each of which the same labor of cutting angular checks must have been encountered."

‡ An illustration of the danger of building on a partially compressible stratum is thus shown, (Hughes on Bridges).

"The piers of a large aqueduct, eleven in number, with two abutments, had all been founded on gravel, a few feet below the surface, and stood well, the masonry appearing without a flaw when they were carried up to their full height, about 50 feet. One of the piers at the south end, however, was founded one part on the gravel and the other on very hard rock, the surface of which was nearly levelled, and the building at once commenced. When carried up to about

are not to be trusted to, especially if lying in an inclined position, as they are liable to slip, and thus cause serious derangement of the superstructure. Much, however, must depend upon the situation of the work. Thus, in building a bridge on inclined strata of this nature, over a ravine or chasm, as shown in Fig. 1, the foundations on the one side would be perfectly secure, whilst those on the opposite side would be always liable to disturbance from the pressure of the inclined strata.



Case 2.—*Bearing stratum affected by exposure to air or to water.*

Soils of this character must be carefully protected from exposure, either by laying the foundations so deep as to be beyond the reach of heat and frost, or by covering the

---

30 feet a formidable fissure was observed from top to bottom of this pier, and the only possible source to which the mischief could be traced was the step of founding the pier partly on the rock and partly on the gravel.

"Had the whole pier been on the rock it would of course have stood without settlement; had the whole been on the gravel it might have settled to a trifling extent, but would have stood as well as the other piers which were founded on the gravel; but placed as it was, partly on the rock, which was entirely solid, and partly on the gravel, which slightly yielded beneath the great pressure upon it, the consequence followed as described above."

foundation-pit with a stratum of concrete. For want of these precautions many buildings with shallow foundations on clay soils become rent and seriously injured, by the contraction and expansion of the ground on which they rest.

Some soils, which are naturally so hard as to require blasting for their removal,* rapidly disintegrate on exposure to the atmosphere, undergoing a chemical action which completely destroys their cohesion. It, therefore, requires considerable caution when laying foundations upon ground which is at all exposed, as, for instance, in throwing an arch over a railway cutting, to guard against this source of danger. As a general rule, when dealing with ground of this expansible and treacherous nature, the less it can be exposed to the air, and the sooner covered up again, the better for the work.

Precautions of this nature are indispensable in cases where work has to be built against an upright face of expansible material, as in the execution of tunnels, sewers, retaining walls, &c., which are liable to be forced out of the upright by the lateral pressure of the soil.†

---

* The chemical action upon clays, and even upon solid rocks, must not be overlooked. Particularly, the well-known action of the air upon shale, which, although so tough and hard under ground, as to require the agency of gunpowder for its excavation, becomes, after a few weeks exposure to the air, thoroughly decomposed.

† Expansion of clay when exposed to the air. "In the tunnel on the Manchester and Bottom Railway, the timbers were frequently broken by the expansion of the clay, although it appeared quite dry. In the Primrose Hill, and the Kilsby tunnels, if the cutting was left for a few days without completing the brick arching, the timbers were broken. The expansion appeared to be nearly the same, whether it was caused by the air, as in the former case, or by the water, as in the latter case. In the "Box Tunnel" it was usual to allow six inches for expansion between the face of the work and the timbers, and that space was scarcely sufficient. At Richmond, a case occured of a well of 4 feet diameter being completely closed in one night by the swelling up of the bottom although there was no water in it.

Case 3.—*Bearing stratum underlying soft ground of considerable depth.*

In cases of this kind, where the expense of bringing up a solid foundation from the hard ground is too great to allow this to be done, a number of supports must be brought up through the soft ground, on which to form a platform to carry the superstructure.

This may be done in a variety of ways, of which the following are those principally employed :

1st. By excavating holes to the depth of the soft ground and refilling them with sand, gravel, concrete, or some equally incompressible material. This system has been much used in Europe. The method usually followed being to drive down a timber pile to the required depth and then to withdraw it and fill the hole with sand.

2d. By driving piles of wood or iron through the soft ground till they rest on the solid stratum.

3d. By screwing piles into the soft ground till they reach firm ground.

4th. By hollow cylinders of cast iron, lowered until they rest upon the bearing stratum, the soft material being removed from the interior of the cylinder, to enable it to descend ; whether driven by impact, lowered by gravity, or forced down by atmospheric pressure.

Case 4.—*Crust of good ground, resting on a treacherous substratum.*

In the treatment of all cases of this kind, it may be laid down as a general rule, that it is best to let well alone, and to abstain from all disturbance of the ground by ramming, driving piles, or similar expedients, taking measures to avoid any wounding of the ground or escape of the substratum. It need scarcely be said that it is important to reduce the weight of the structure as much as possible, and to distribute

it over a large area of bearing surface. When the substratum is simply compressible it may sometimes be brought to its extreme settlement by *weighting* the foundations before commencing the superstructure, which may afterwards be carried up without fear of subsequent movement.

If the substratum be soft soapy clay, care should be taken to avoid exposing it by cutting deep ditches or drains in the neighborhood of the work, as this might cause extensive slips. If the substratum be of sand there will probably be little or no settlement, so long as it remains undisturbed, but, if exposed to the action of water, no dependence can be placed upon such ground, as it will be always liable to be undermined. Thus a chimney might stand perfectly secure for many years upon a substratum of dry sand and be undermined and destroyed in a few days by sinking a well near it, or even by laying in a drain at some considerable distance from its site. We may here remark that the numerous instances of failure which have at different times occurred from the escape of sand and loose ground from below buildings, which would otherwise have been perfectly secure, shows the great attention and care required in executing drainage works in the neighborhood of existing buildings. Many buildings about London have undergone serious settlement during the last few years, in consequence of the morass, from which the district takes its name, having become thoroughly drained by the construction of new sewers. At the "London Institute," the outer walls were built on the substratum of gravel underlying the peat, whilst the inner walls rested on the peat itself, which, being prevented from spreading by the outer walls, formed a good bottom so long as it remained wet, but on the formation of the new sewerage they began to sink, and it was found necessary to underpin them with concrete—an operation which was successfully performed.

This instance of failure affords a lesson as to the insufficiency of sheet piling round a building to prevent settlement when the substratum is full of water.

DIVISION B.

CLASS I.—Foundations Under Water.

If the ground be not exposed to scour, and does not underlie a soft stratum, we can safely lay our work simply on the ground, and this may be done under water by a variety of means. If, on the other hand, there is a liability to scour, or the firm ground is covered by soil, which must be removed before commencing the work, it becomes necessary, temporarily, to exclude the water from the site of the foundation, by means of caissons or coffe1-dams.

Case 1.—*Pile Foundations.*

Timbe rpiles are objectionable when partly out of water, as they are liable to decay at the water line. In tidal waters also, timber is soon attacked by the worm and becomes rapidly destroyed. Neither is the action of the worm confined to salt water.

Hollow Cast-Iron Piles.

These may be considered as large hollow piles. They may be made to descend simply by gravity, the ground in the interior being excavated, so as to allow them to descend by their own weight, or they may be forced down by atmospheric pressure.

CLASS II.—Solid Foundations Laid Under Water.

Case 1.—*Piérre Perdue, or Random Work.*

This method consists in throwing masses of stone into the water, and leaving them to arrange themselves. This is not

a system of construction that can be adopted in rivers, where it is of consequence to avoid contracting the water-way, but it is made use of in sea works, for the construction of breakwaters, jetties, &c. It is not, however, to be depended on in situations exposed to the run of the sea, as a base for any permanent erections, as wharf walls, light-houses, &c.

Case 2.—*Random Blocks of Béton.*

The insecurity attending works erected on a foundation of piérre perdue led the French engineers engaged on the harbor works at Algiers to substitute for the ordinary sized blocks of stone, previously used, large masses of béton, of such size as to be immovable by the waves. Except in some few special cases, it was practically impossible to employ stones sufficiently large to fulfill this condition ; but there are few situations where it is not possible to manufacture artificial blocks of béton of from ten to twenty tons weight, which may with great ease be floated to the spot where they are to be immerged.

Case 3.—*Béton Laid in Caissons, Lined with Tarpaulin.*

This method of using béton has been recently brought into notice by its adoption in portions of the work at Algiers; and it is exceedingly well adapted to forming foundations on a rugged rock bottom in shallow water, where it is desirable that the work should be brought up with a face vertical, or nearly so, to avoid contracting the water-way, or to allow vessels to come alongside a wharf. The caisson employed is a large box, without bottom or top, the sides of which are roughly cut, to suit the irregularities of the rock on which it is placed. It is lined with tarpaulin, which is allowed to adapt itself freely to the bottom, and prevents all danger of the newly-laid béton being injured by the action of bottom springs, or by the run of water through the cavities left be-

tween the rock and the sides of the caisson. The béton is lowered to the bottom of the caisson in a box with a movable bottom, by which contrivance it is deposited in a solid mass, without any risk of the lime being washed out, which is always the case, more or less, when concrete or béton is dropped through water without any protection of this kind. When the mass thus formed by successive deposits reaches the surface of the water, it is left for some days to become hard, and when this has taken place, the sides of the caisson are removed, and the cloth lining cut away, to be used again in the formation of the next length. This method of constructing foundations appears especially adapted to the case of an uneven rock bottom, in situations where the construction of a water-tight coffer-dam, and the levelling of the rock to receive regular masonry would be attended with heavy difficulty and expense.

CLASS III.—Foundations from the site of which the water is temporarily excluded.

Case 1.—*Solid masonry sunk in caissons or chests of timber, of which the bottoms rest on the surface of the ground.*

This system is but little used. If the ground be soft or loose the foundation is liable to be undermined; if it is hard there is great difficulty in forming a level bottom, and the cross-strain thrown in consequence upon the unsupported parts of the timbers leads to fractures and dangerous movements in the superstructure.

Case 2.—*Masonry built in caissons grounded upon a bed of béton.*

This is a method of using caissons which is quite free from the objections just named. If there is any liability to

scour the ground must be dredged out to a sufficient depth before putting in the béton. This system is used in Europe.

Case 3.—*Masonry built in caissons resting on a pile foundation.*

This is a very economical system, and well adapted to situations where there is a liability to scour, or where the bearing stratum is at a considerable depth. The piles having been driven down until a firm bottom is reached are cut off to a uniform level, as near the ground as possible, and the caisson is lowered upon them, the timbers forming the bottom of the caisson, being disposed so as to rest on the pile-heads. This method of forming foundations, is not extensively practiced but was adopted with great success in the Lary bridge at Plymouth, Eng.

CLASS 4.—Foundations of an Artificial Bearing Stratum.

Case 1.— *Ground soft, but not fluid.*

We may treat ground of this kind in two very different ways.

1st. We may consolidate the soft ground by driving piles into it until it becomes compressed, so that the piles are prevented from sinking by latteral pressure.

2d. We may interpose a platform of fascines, timber or concrete, between the surface of the ground and the superstructure, thus distributing the weight of the latter over a large extent of bearing surface.

These methods are often combined. A very usual method of proceeding, is to surround the site of the work with sheet-piling, to prevent the escape of the soil, which is then consolidated by driving piles into it at short distances from each other. The piles are then sawn off level, the ground between them removed for two or three feet deep, the exca-

vation filled up with concrete, and the whole is then planked over to receive the masonry of the superstructure.

Sometimes the planking is laid, not on the heads of the piles, but on a network of horizontal timbers. The practice of driving piles into soft ground to consolidate it is not to be recommended, its effects being usually to pound up the soil and to bring it into a state like *batter*. Instead of *driving* piles in these cases, a much better plan is to *bore* holes with a large auger to a considerable depth and to fill them with sand, which from its property of acting almost like a fluid, is a most valuable material for distributing pressure over a large area of surface. In the case of a timber pile the pressure is transmitted only in the direction of its length, but a sand pile transmits the pressure laid on it not only to the bottom but to the sides of the excavation, and does not injure the ground by vibration.

In many soils where the ground is too soft to carry the weight of the walls of a building without artificial aid, a wide trench filled with dry sand will be found a more effective precaution against settlement than the use of timber planking, concrete, or any other expedient which simply distributes the pressure in a vertical direction.

CASE 2.—*Soil of a semi-fluid nature, as mud, silt or peat.*

Cases of this kind occur chiefly in navigation and drainage works, and are difficult to treat successfully. The principle to be kept in view is the formation of a firm platform on which the work shall be allowed to float, as it were, on the fluid soil, into which it will sink to a considerable depth. This must be allowed for in the construction of the work, and, if possible, the foundation should be loaded to the full weight of the superstructure before the latter is commenced, so as to avoid any considerable movements after the completion of the work.

The great point to be attended to is the *equal distribution* of the weight of the structure over the foundation, which will then settle in a vertical direction, and cause little injury, whereas an irregular settlement would rend the work from top to bottom.

ON FOOTINGS.

Footings answer two important purposes.

1st. By distributing the weight of the structure over a large area of bearing surface the liability to vertical settlement from the compression of the ground is greatly diminished.

2d. In the case of isolated structures standing on a comparatively small base they form a great protection against the danger of the work being thrown out of the upright by the action of the wind. For example, the case of a chimney stack 100 feet high standing on a base 10 feet square, and exposed to gales. The compression of the ground to leeward to the extent of .025 foot would be sufficient to cause the top of the stack to overhang six inches.

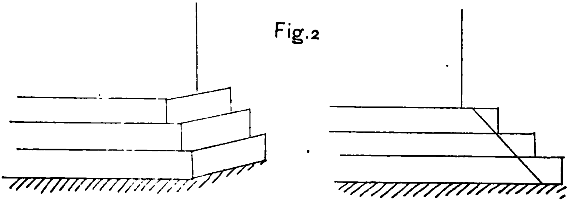
If, however, we increase the base to 20 feet square, we not only double the leverage with which the foundation resists the force of the wind, but the bearing surface is quadrupled, so that the total resistance is eight times greater than in the first instance.

Footings, to have any useful effect, must be securely bonded into the body of the work, and of sufficient strength to resist the violent cross-strains to which they are exposed. The neglect of this, causes many disastrous failures. It should be remembered that the lower any stone is placed in a building the greater weight it has to support, and therefore the greater the risk arising from any irregularities in the working of the beds, which should be dressed perfectly true, and with as much, or even greater care, than in the up-

per part of the work. No back joints should be allowed beyond the face of the upper work, except where the footings are in double courses, and every stone should bond into the body of the work several inches at least.

3d. Each footing stone beyond the one above it must be reduced in proportion to the weight of the superstructure, or the cross-strains thrown on the projecting portion of the masonry will rend it from top to bottom, as shown below.

Fig. 2



In building large masses of work, such as the abutments of bridges, and the like, the proportionate increase of bearing surface obtained by the projections of the footings is very slight, and there is great risk of the latter being broken off by the settlement of the body of the work. It is, therefore, usual to give very little projection to the footing courses, and to bring up the work with a battering face, or slight offsets. Footings of undressed rubble built in common mortar cannot be too much reprobated, as the compression of the mortar is sure to cause movements in the superstructure. A much safer way of using rubble is to break it up tolerably small and lay it in the trenches without mortar, as it forms a hard, unyielding bottom, so long as it is prevented from spreading laterally by the pressure of the ground. Where the building material is small rubble the best way is to lay the foundation with cement mortar, so that the whole will form a solid mass, in which case, the size, shape, and dressing of the stone is of little consequence. In cases

where the ground is soft, and a large extent of base is requisite, the expense attendant on spreading out the solid work to the requisite extent renders it necessary to adopt some cheaper method.

1st. To put in a wide footing course of timber.

2d. To put in a layer of concrete, which may be considered as a footing course of artificial stone, having, however, but little transverse strength, and consequently requiring the depth of the stratum to be proportional to its projection.

3d. To build upon a layer of sand or similar material, which, pressing against the sides as well as against the bottom of the foundation-pit, distributes the weight of the superstructure over a large resisting surface.

ON PLANKING.

Where a large bearing surface is required planking may be resorted to, provided the timber can be kept from decay. If the ground be wet there is nothing to fear, but in a dry situation, or one exposed to wet and dry, no dependence can be placed on unprepared timber.

The advantage of timber is that it will resist a great cross-strain with trifling flexure, and therefore a wide footing may be obtained without much spreading of the bottom courses of masonry. Under walls, cut the stuff in short lengths and place across the foundation, then tie by longitudinal planking, and spike. In planking foundations, such as those for abutments of a bridge, it is better to lay the planking in two thicknessess, crossing joints and spiked together, and laid, crossing the courses of masonry diagonally. This makes sounder work than if the joints of the planking were parallel to those of the masonry.

SAND, CONCRETE, AND BÉTON.

We here name, in the relative order of their value as artificial foundations, three methods of forming a hard bearing stratum, for distributing the weight of a building over a large area of compressible ground, or for bringing up a solid foundation from a considerable depth where there are objections to the use of masonry or timber for effecting that object.

SAND.

The use of sand, with its value as a means of distributing weight, has been known from a very early period, but it has been very little adopted in this country. It may at first sight seem paradoxical, that a loose substance such as sand, having no cohesion amongst its particles, and proverbial for its instability, should be of any use as a material for foundations, especially when we consider that it is very similar to a fluid, and if unsupported, can scarcely be made to stand at any slope whatever. It is, however, to these very qualities that it owes its value, which consists in distributing the weight laid upon it, not only in a vertical, but in a horizontal direction, the lateral pressure exerted against the sides of the foundation-pit, greatly relieving the bottom. In very soft ground, of course this system of construction cannot be adopted, as the sand would work itself gradually down, but in all situations where the ground, although soft, is of a tolerable consistency, so that the sand is confined, the use of this material is attended with many advantages as regards cost and stability of work. There are two methods of using sand, viz. : in layers and as piles. In forming a stratum of sand the soft ground should be taken out several feet in depth, and the sand well rammed as it is thrown in, so as to ensure its being thoroughly forced into the sides of the

foundation-pit, after which there will be very little, if any, risk of irregular settlement.

The surface of the sand may be protected in a variety of ways :—by planking, paving, or otherwise, according to the nature of the materials at hand, but care should be taken to lay the masonry of the superstructure at sufficient depth to prevent all risk of scour from surface water, or from any other accidental source of injury.

Sand-piling is a very economical and efficient method of forming a foundation under some circumstances where timber-piling is usually resorted to. It would not, however, be effective in very loose, wet soils, as the sand would work into the surrounding ground. In situations where the stability of piles arises from the pressure of the ground around them these sand-piles are found to be of more service than timber ones, because of their ability to transmit pressure, not only against the bottom but against the sides of the hole it fills, and thus acting on a large area of bearing surface. A layer of small broken stone, gravel, or any similar hard material, will be found also of great service when distributed over the area of a foundation. Our own experience leads us to feel, that unless the lime used in the composition of concrete is such as to ensure the formation of a mass which shall at once become firm and solid throughout, it will be better, under ordinary circumstances, to use gravel in a loose state, merely ramming it, to force it thoroughly into the sides of the trenches.

CONCRETE.

The term as here applied, refers exclusively to that made of gravel concreted, with lime mortar. As generally made, concrete is nothing more than a weak artificial stone possessing little strength when exposed to transverse strain. The most prudent course in putting in a concrete foundation is

to force the concrete into the trenches, ramming it continually, so that it shall exert considerable lateral pressure. It is a common practice to make the concrete course exactly of the specified width, irrespective of the extent to which the trenches have been excavated. This is very improper. The whole extent of excavation should be filled in with concrete, and rammed solidly against the sides of the pit. Another wrong practice is that of throwing the concrete into the foundation-pits from a raised stage, with a view to consolidate it. The contrary effect is produced; for this practice not only tends to separate the particles which have previously been brought into close contact, but that the admission of the air into the mass renders it less compact, and tends to prevent the lime and sand from properly entering into combination with each other. The concrete should be tipped from the barrow as close to the surface as possible, and kept constantly rammed as the work proceeds, so that no vacuities shall remain in any part.

It is preferable that it should be brought up in layers not exceeding twelve inches thick, the wheelers working gradually round the whole area, and being followed by the rammers, so that no vertical junctions exceeding twelve inches in height can occur at any point. Concrete is a valuable material when applied in a proper manner, viz: in underground works, where it is confined on all sides, and is consequently subjected to little cross strain; but it is not fit to be used above ground as a substitute for masonry, and will not bear exposure to water. The lime and gravel should be thoroughly incorporated, by being repeatedly turned over with shovels, sufficient water being added to ensure the thorough slacking of the lime, without drowning it. Concrete should not be thrown into water, because ordinary stone lime will not set under any circumstances, and it should be carefully protected from any wash or run of water, which would have

the effect of washing out the lime and leaving the concrete in the state of loose gravel. Concrete made in this way swells slightly before setting, which makes it valuable for underpinning foundations, etc.

BÉTON.

Béton is to be lowered into the water in a box, with a bottom so constructed that it can be opened and its contents discharged by pulling a cord, so as to deposit the béton on the bottom without having to fall through a depth of water which might wash away the cement. For the same reason it is necessary, before commencing to lay the béton, to surround the site with sheet-piling, to protect it from the action of the water. The ordinary method of using béton in Europe, is in alternate layers of béton and rubble stone. A layer of béton, about a foot thick, is first spread over the whole area of the foundation, and on this is laid a stratum of rubble, which, sinking into the soft béton becomes thoroughly incorporated with it, on this is laid another layer of béton, then a course of rubble, etc. In the works at Algiers, blocks of béton were formed in the water on the site, immersed in lined caissons, as follows : the sides of the caisson are formed of a framework of timber, lined on the inside with double layers of planking, crossing joints, the bottom being cut to the profile of the ground. They are also lined on the inside with tarred cloth, which forms a kind of sack; this cloth is nailed to the wood-work and extends the whole height of the caisson up to twenty inches above the level of high water. The four sides of the caisson are connected by hinged angle-irons, so that they can be easily unshipped. They are taken up at the end of ten or twelve days, and can be used again by again fitting them to the shape of the ground. When fixed together a cloth is fitted to them, which must be of sufficient size to adapt itself to all the irregularities of the

bottom that it covers. The mass of béton which fills it can then mould itself perfectly to the ground, and connect itself with it by the very irregularities of the latter. The Italians used this method of making artificial blocks when they wished to repair breaches that took place in masonry under water. All that is wanted to succeed in forming blocks of large dimensions is to make the sack so strong that it shall not burst, and to fill it with béton on the very place where it is wished to immerse the block. Whenever béton is immersed in water which may be agitated before its setting, or whereverit may be lowered into a foundation-pit where there are bottom springs, it is imperatively necessary that it should be completely protected from wash.

CAISSONS.

We have already spoken of the danger attendant upon sinking caissons upon the natural bottom, on account of the difficulty of forming the latter to a level bed, in default of which the cross strain caused by any irregularities of the surface would be productive of serious injury. But, there are cases of soft ground in which the only available mode of putting in a foundation is by sinking it piecemeal in caissons, loading them until they have compressed the mud in which they are grounded, to such an extent that no reasonable fear can be entertained of their sinking further with the weight of the superstructure, and, provided there is no tendency to scouring below the bottom of the caissons, such foundations are the very best that can be formed under such circumstances.

During the erection of the Lary Bridge, near Plymouth, England, it was found that a gradual scour of the bed of the river was taking place, and that some protective measures were necessary, in addition to the sheet piling, to prevent the undermining of the foundations. It was, therefore, determin-

ed on forming an artificial bed to the full extent to which the natural one was removed, with clay from eighteen inches to two feet thick, covered with rubble stone of all sizes, from two hundred pounds downwards. This plan was successful. By this union of material an indistructible bed has been produced. The clay shields the natural bed from the current, whilst, at the same time, it forms a tenacious cement in which the stone buries itself, and which is hardened by the volume of water constantly pressing on it.

COFFER-DAMS.

They are usually constructed of timber piles driven close together in rows round the site of the work, the space between the rows being filled with puddle. The number of rows of piles and the thickness of the puddle walls must depend on the situation of the work. In some cases bags of clay piled on each other may be used, in others, rough caissons without top or bottom, filled with clay and sunk in line around the space to be enclosed may be used. Coffer-dams are sometimes formed in shallow water with a single row of sheet-piling, but this is very precarious work, as unless the piles are fitted together with great accuracy before driving, and are driven true, it is impossible to keep the joints close to prevent leakage. A single row of sheet-piling may, however, be often used with great advantage as a protection and support in front of an earthen dam. In rivers subject to heavy freshets it is common in constructing coffer-dams to keep the top of the dams below the flood level, as it is generally less expensive to pump out the water than to construct and maintain a dam which should sustain the pressure of the flood waters ; and it is always advisable to provide every dam with a sluice, by means of which the water can be admitted if there is fear of a sudden freshet. The principal difficulties in the construction of coffer-dams, are as follows :

1st. To obtain a firm foothold for the piles, which, in either rock or mud, is difficult.

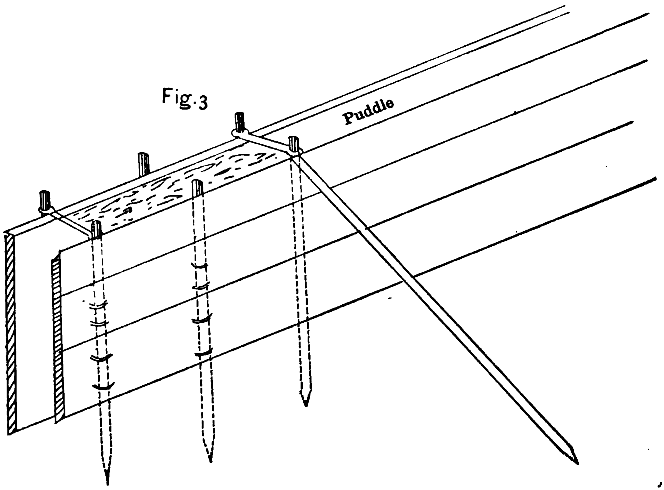
2d. To prevent leakage between the surface of the ground and the bottom of the puddle.

3d. To prevent leakage through the puddle wall.

4th. To keep out the bottom springs.

In the case of rock bottom, the use of timber piles driven in the ordinary way would be impossible. In such cases, the usual guide piles are dispensed with, and iron rods "jumped" into the rock (see fig. 3,) are substituted for them, the sheeting of the dam being formed by horizontal planking secured to the rods by rings, which allowed them to be pushed down into the water until each plank rested on the one below it, the bottom plank being cut as near as possible to the profile of the surface of the rock. In soft ground there is as much difficulty in securing the guide piles as in rock.

Fig. 3



Cases of this kind may be successfully treated by the use of screw piles with a broad flange.

Leakage between the puddle and the surface of the ground will generally take place, unless all the loose, soft or porous surface soil be carefully removed before any of the puddle is put in. This may be done before or after the piles are driven. The best plan is to dredge for a portion of the depth required before commencing the driving, which is much eased thereby, and afterwards to dredge out a trench between the rows of piles, deep enough to allow the puddle to lie well below the ground line. Leakage through the puddle wall itself may arise from various causes, but may generally be prevented by careful work and selection of good material.

In the first place, the piles should be all fitted to each other before driving, and should be truly driven ; next, the framing and strutting should be strong, to prevent any straining or movements under the varying pressure to which the dam may be exposed by alterations in the height of the water ; and lastly, the material used for puddle should be such as will settle down into a solid mass, and should be carefully rammed in thin layers, so as to ensure that no vacuities are left in any part. For this reason it is desirable, when the piles have been driven between double walings, to remove the inside wales after the piles are driven home, as any projections of this kind increase the difficulty of ramming the puddle. In order to resist the evil effects which might arise from the swelling of the puddle, the inner and outer row of piles are usually connected with iron bolts, passing through the piles, and secured by nuts with iron plates and large wooden washers, to prevent the former from being drawn into the piles by the extreme pressure. These tie-bolts are often found to be very troublesome sources of leakage, as the water soaks in around the bolt holes, and it is

difficult to keep the puddle from settling away from the bolt and leaving a channel for the passage of water through the dam. In the Grimsby dam this was guarded against in an effective manner. The dam consisted of a double puddle wall, inclosed by three rows of piling, and the tie-bolts only passed through half the total thickness of the dam, and were fixed so as to break joints with each other, so that no water could find its way through from this cause. The first step to be taken in forming a coffer-dam (after the ground has been prepared by dredging) is to drive guide piles at short intervals along the line of the dam and to bolt on to them horizontal timbers, called "walings," to guide the sheet piles in their descent. The guide piles are always of whole timbers, the walings of scantling. Guide piles are generally placed about ten feet apart in the length of the dam. If the sheet-piles are of whole timbers, the wales may be bolted on each side of the guide piles, so that the latter become portions of the sheeting ; but if the sheet-piles are scantling or plank, the wales are both bolted on the inside of the guide piles, a sheet-pile being driven first, behind each pile, to keep the wales at the proper distance from each other. The selection of proper material for puddle is a point of importance. The clay should be thoroughly worked up with the gravel before being thrown into the dam ; this lessens the tendency to cracking, and makes a more compact and binding mass than clay alone. The great point of importance is to leave no large lumps, but to break up the material very small before using it, and to ram it carefully, so that no vacuities be left in any part. Coffer-dams have been successfully employed constructed of timber piles and framing in a single sheet, made staunch by a sheet of water-proof canvass,(india rubber) stretched over the surface, and immersed in a puddle trench at the bottom, thus dispensing with the double row of piling and with almost the whole of the puddle.

PILE DRIVING.

Formula which gives the force of the blow in terms of the weight and fall of the ram.

The momenta of falling bodies are as the products of their weights by their velocities.

The velocity acquired by any falling body is directly as the time occupied in its descent.

The spaces fallen through are as the squares of the times of descent, a body falling freely in a vacuum falls through $16^1/_{12}$ feet in the first second, and the velocity acquired at the expiration of the first second is $32^1/_6$ feet per second.

Let weight of ram $= w$.

Fall of do., in feet $= f = 16^1/_{12} \times s^2$.

Time of descent in seconds $= s = \sqrt{\dfrac{f}{16^1/_{12}}}$

Velocity of ram at moment of striking pile $= v = 32^1/_6 \times s$

$$= 32^1/_6 \sqrt{\frac{f}{16^1/_{12}}} = 2\sqrt{16^1/_{12} f}$$

Momentum in force of blow $= m = wv = w\ (2\ \sqrt{16^1/_{12} f}$

In driving sheet-piling, the piles are kept in the proper position by horizontal pieces of timber, called wales, which are fixed to guide piles previously driven. In driving coffer-dams and similar work, the wales are seldom placed below the water line.

When sheet-piling has been driven round the foundations of any work, as in forming a coffer-dam round the pier of a bridge, there will always be, in the event of its being drawn, the risk of the ground settling down to fill up the vacancy caused; but in clay or marl soils this is not the greatest danger, for the water scours out and enlarges the race thus formed, and the bottom speedily becomes broken up, nearly to the depth to which the piles were driven.

As a general rule, it may be laid down that piles in such situations should never be drawn, but should be cut off at the level of the ground.

MASONRY.

COMPOSITION AND RESOLUTION OF PRESSURES.

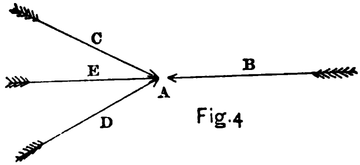
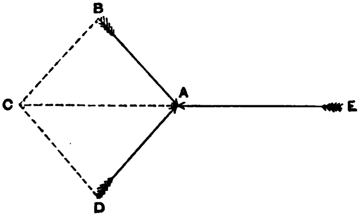


Fig. 4

Let A, Fig. 4, be a body acted on by three pressures, whose directions and amounts are represented by the three arrows *B*, *C* and *D*, and are so related and adjusted that, by their joint action, the body A is in equilibrium, that is, has no tendency to move in any direction. Now, let us suppose two of the forces, *C* and *D*, to be suddenly removed, and a new force, E, substituted for them, in a direction directly opposite to the pressure B, and in amount exactly equal to it. Now, when a body is acted upon by equal forces, whose directions are exactly opposite, it is in a state of equilibrium, and therefore it is evident, that in the substitution which we are just supposed to have made, we have not in any way affected the body *A*, and that the force *E*, produces the same effect as did the two pressures *C* and *D*, whose places it has taken. Any pressure which will thus take the place of two or more pressures, producing precisely the same results, is said to be the *resultant of those pressures*, and the process by which the direction and amount of the resultant of any pressures is found, is termed the *composition of forces;* while the reverse process, by which we find two or more pressures which would produce the same effect as any one given pressure, is called the *resolution of forces.*

*The resultant of any two pressures is represented, both in direction and amount, by the diagonal of a parallelogram, whose two adjacent sides represent, in direction and amount, those two pressures.**

Fig. 5



Thus, let BA, and DA, Fig. 5, be two pressures, acting upon the body A; draw CB, parallel and equal to DA, and CD, parallel and equal to BA, so as to complete the parallelogram $A\ B\ C\ D$, to which draw the diagonal CA ; then will CA represent, both in direction and amount, the resultant of the two pressures BA and DA. Let EA represent the pressure which is required to keep the body A in equilibrium, and prevent its being moved by the pressures BA and DA ; then it is evident that EA must be equal and opposite to CA, and the three pressures BA, DA and EA, by which the body A is kept in equilibrium, are parallel in direction and proportional in amount to the three sides BA, CB, and AC, of the triangle $A\ B\ C$. Or generally, *any three pressures which, when applied to a body, keep it in equilibrium, are all in the same plane, and are parallel and proportional to the three sides of a triangle.*

---

* The following formulæ express the magnitude and direction of the resultant of any two pressures. Let P^1 and P^2 represent two pressures, P^2 being the greater; let B be the angle formed by their two lines of direction, R their resultant, and V the angle which its line of direction makes with that of P^2, then

$$R = \sqrt{(P^1)^2 + (P^2)^2 \mp P^1 P^2 \operatorname{Cos} B}$$

$$\text{Tang. } V = \frac{P^1 \operatorname{Sin} B}{P^2 \mp P^1 \operatorname{Cos} B},$$ in which the upper sign is to be taken when B is less than 90°, and the lower when it is greater.

When any three pressures act upon a body in directions which do not lie in the same plane, then is the resultant of those pressures represented, both in magnitude and direction, by the diagonal of a parallelopipedon, whose three contiguous edges represent, both in direction and amount, the three given pressures.

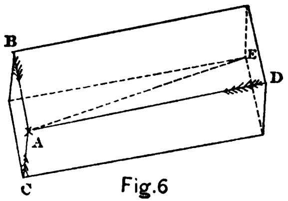


Fig.6

Thus, let BA, CA and DA, Fig. 6, be the three given pressures, all acting at the point A; construct the parallelo pipedon shown in the figure; then will the diagonal EA represent, both in direction and amount, the resultant of those three pressures.

The resultant of any number of pressures, acting in any direction, may be found by the following method: first proceed to find the resultant of any two of the pressures, considered without reference to the others; then find the resultant of this resultant and another of the pressures; then of this second resultant and some other of the pressures; and thus proceed until the number of the pressures left is only two, when the resultant of those two, being found by one of the methods just explained, will be the resultant of the whole.

MOMENTS OF PRESSURE.

When the effect of a pressure, whose direction is in any given plane, is considered with reference to some point in that plane not situated in the direction of that pressure, such effect depends not only on the amount of the pressure, but

also on the perpendicular distance of the point from the direction of the pressure; and the product of the pressure, multiplied by the perpendicular distance of its direction from the point, is termed the moment of the pressure about that point. For example, if *B*, fig. 7, represents a pressure of 9 pounds, acting in the direction *AC*, and it be desired to measure its moments about the several points *DE* and *G*; if *BD*, the perpendicular distance of the line *AC* from the point *D*, $= 5$; *EP*, the distance of *AC* from the point *E*, $= 4$; and *GH*, the distance of the point *G* from the line *AC*, $= 8$; then $9 \times 5 = 45$ will be moment of *B* about the point *D*; $9 \times 4 = 36$ its moment about the point *E*; and $9 \times 8 = 72$ its moment about the point *G*.

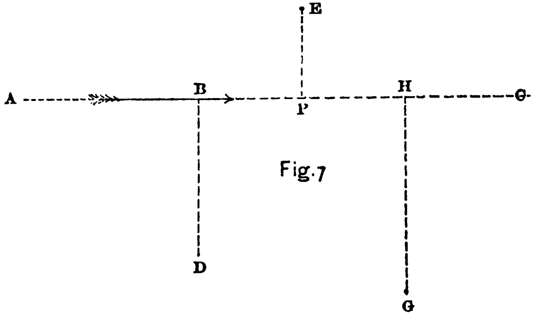


Fig. 7

It is customary and very convenient to represent pressures by lines drawn on paper, the general direction of the lines being the same as that of the force, and the length of the line being proportional to the amount which it represents. For example, suppose a line $1/_{10}$ of an inch in length to

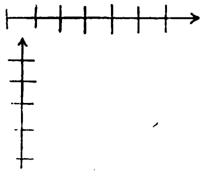


Fig. 8 *a*.

represent a pressure of one pound, then fig. 8 would represent two pressures, whose directions were at right angles to each other, and equal to 5 and 7 pounds respectively ; the arrows at the same time serving to show the directions in which the pressures act.

PARALLEL PRESSURES.

If the directions of any number of pressures are parallel to each other, then the direction of their resultant is parallel to them; and, if they all act in the same direction, is equal in amount to the sum of all the pressures; but, if some act in one direction, and some in another, then is their resultant equal to the difference of the sums of those pressures which act in each direction.

The moment of the resultant of any number of parallel pressures, measured from any given plane parallel to their directions, is equal to the sum of the moments of all those pressures, measured from the same plane.

THE LIMITING ANGLE OF RESISTANCE.

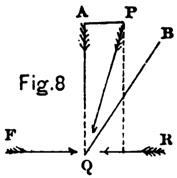
(Called by some writers the angle of repose.)

Any pressure applied to the surface of an immovable solid body, by the intervention of another body movable upon it, will be sustained by the resistance of the surfaces of contact, whatever be its direction ; provided only, the angle which that direction makes with the perpendicular to the surfaces of contact, does not exceed a certain angle, called the Limiting Angle of Resistance, of those surfaces.

This is true, however great the pressure may be. Also, if the inclination of the pressure to the perpendicular exceed the limiting angle of resistance, then this pressure will not be sustained by the resistance of the surfaces of contact ; and this is true, however small the pressure may be. The

angle above referred to is described as "the state bordering upon motion of one body upon the surface of another;" also, the resultant pressure upon their common surface of contact, is inclined to the normal (perpendicular) at an angle whose tangent is equal to the co-efficient of friction.

Fig.8



Let PQ represent the direction in which the surface of two bodies are pressed together at Q, and let QA be a perpendicular or normal to the surfaces of contact at that point; then will the pressure PQ be sustained by the resistance of the surfaces, however great it may be, provided its direction lie within a certain given angle, AQB, called the limiting angle of resistance; and it will not be sustained, however small it may be, provided its direction lie without that angle. For, let this pressure be represented by PQ, and let it be resolved into two others, AQ, and RQ, of which AQ is that by which it presses the surfaces together perpendicularly, and RQ that by which it tends to cause them to slide upon one another; if therefore, the friction F, produced by the first of these pressures, exceed the second pressure RQ, then the one body will not be made to slip upon the other by this pressure PQ, however great it may be. But if the friction F, produced by the perpendicular pressure AQ, be less than the pressure RQ, then the one body will be made to slip upon the other, however small PQ may be. Let the pressure in the direction lQ be represented by P, and the angle AQP by θ, the perpendicular pressure in AQ is then represented by $P\ Cos.\ \theta$, and therefore the friction of the

surfaces of contact by f P *Cos.* θ, f representing the co-efficient of friction. Moreover, the resolved pressure in the direction $R\,Q$, is represented by P *Sin.* θ. The pressure P will therefore be sustained by the friction of the surfaces of contact, or not, according as P *Sin.* θ is less or greater than f P *Cos.* θ; or, dividing both sides of this inequality by P *Cos.* θ, according as tang. θ is less or greater than f.

Let, now, the angle $A\,Q\,B$ equal that angle whose tangent is f, and let it be represented by φ, so that tang. $\varphi = f$. Substituting this value of f in the last inequality, it appears that the pressure P will be sustained by the friction of the surfaces of contact, or not, according as tang. θ is greater or less than tang φ; that is, according as θ is greater or less than φ, or according as $A\,Q\,P$ is greater or less than $A\,Q\,B$.

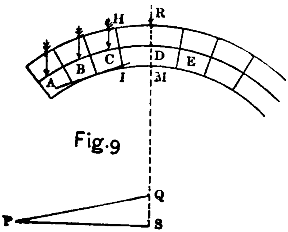


Fig. 9

EQUILIBRIUM OF ARCHES.

An arch is said to be in equilibrium when the strain of its parts has no tendency to alter its form.

Let *A B C*, &c., Fig. 9, be the separate stones or voussoirs of an arch, whose several parts are in equilibrium. Now, each stone is acted upon by three forces, namely: the weight of itself and the load above it, acting in a vertical direction, and the pressure of each of the two contiguous stones acting in directions perpendicular to their surfaces of mutual contact. Then, since these forces must all be in equilibrium,

their lines of direction must all intersect in some common point within the stone. Let *A B C*, &c., represent these points in the several stones composing the arch shown in Fig. 9; then if lines *AB*, *BC*, *CD*, &c., be drawn, connecting these points, they will represent the directions in which the stones press on each other; and the line *A B C*, &c., is termed the line of pressure of the arch. Now, although the pressure of one stone upon its neighbor, as *D* upon *C*, is actually spread over the whole surface of the joint *HI*, we may, without in any way affecting the question under consideration, suppose the whole pressure collected in the point in which the line of pressure cuts the joint *H I*, and similarly of all the other stones; so that if we conceive the whole weight of each stone, and of the load which it supports, to be collected in (or, which is the same thing, suspended from) the points *A*, *B*, *C*, &c., and those points to be connected by inflexible bars, *AB*, *BC*, *CD*, &c., (themselves devoid of weight,) we shall in no wise alter or disturb the state of equilibrium of the arch. We see, then, that when we deviate so far from the arch of equilibrium as to cause the line of pressure to approach either the intrados or extrados of the arch, we begin to endanger its stability, actual contact with either being the ultimate limit; and the stability of the arch being greater as we make the line of pressure approach nearer to the centre of the joints.

In an arch in equilibrium, the horizontal pressure on the keystone is equal to the weight on a foot of the surface of the same, multiplied by the radius of the arch in feet. The power of an arch to resist the horizontal strain at the crown is proportional to the depth of the keystone, and to the cohesive power of the material of which the arch is composed. The stability of an arch is therefore directly proportional to the depth of its keystone, multiplied by the cohesive power of the material; and is inversely proportional

to its radius of curvature, multiplied by the weight on every foot of its surface.*

A structure may yield under the pressures to which it is subjected, either by the slipping of certain of its surfaces of contact upon one another, or by their turning over upon the edges of one another; and these two conditions involve the whole question of its stability.

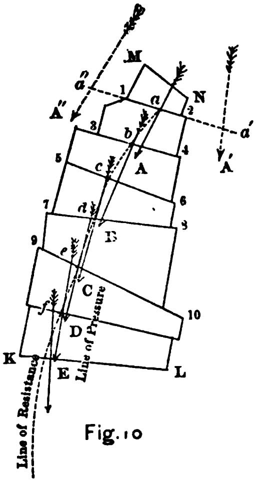


Fig. 10

THE LINE OF RESISTANCE.

Let a structure $MNLK$, composed of a single row of uncemented stones of any forms, and placed under any given circumstances of pressure, be conceived to be intersected by

* Let R be put for the radius of curvature of an arch at its crown; d, for the depth of its keystone, and b, for the breadth of the arch, all in feet; also, let w equal the vertical weight on every square foot of the keystone, including its own weight; P, equal the horizontal pressure upon the keystone; and c, the weight required to crush a square foot of the material of the arch, all in pounds; then $P = Rbw$, and the stability of the arch will be proportional to $\frac{dc}{Rw}$, which expresses the number of times that the strain upon the arch is less than that which would cause it to yield by crushing at the keystone.

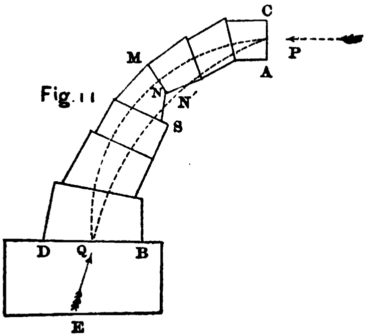
any geometrical surface 1, 2, and let the resultant aA of all the pressures which act upon one of the parts MN 1, 2, into which this intersecting surface divides the structure, be imagined to be taken. Conceive then this intersecting surface to change its form and position so as to coincide in succession with all the common surfaces of contact 3, 4, 5, 6, 7, 8, 9, 10, of the stones which compose the structure, and let bB, cC, dD, eE, be the resultants similarly taken with aA, which correspond to these several planes of intersection. In each such position of the intersecting surface, the resultant spoken of, having its direction produced, will intersect that surface, either within the mass of the structure, or, when that surface is imagined to be produced, without it.

If it intersect it *without* the mass of the structure, then the whole pressure upon one of the parts, acting in the direction of this resultant, will cause that part to turn over upon the edge of its common surface of contact with the other part. If it intersect it *within* the mass of the structure, it will not. Thus, for instance, if the direction of the resultant of the forces acting upon the part NM 1, 2, had been $a'A'$, not intersecting the surface of contact 1, 2, within the mass of the structure, but, when imagined to be produced beyond it to a', then the whole pressure upon this part acting in $a'A'$ would have caused it to turn upon the edge 2 of the surface of contact 1, 2, and similarly, if the resultant had been in $a''A''$, then it would have caused the mass to revolve upon the edge 1. The resultant having the direction aA, the mass will not be made to revolve on either edge of the surface of contact 1, 2.

Thus the condition that no two parts of the mass should be made by the insistent pressures to turn over upon the edge of their common surface of contact is involved in this other, that the direction of the resultant, taken in respect to every position of the intersecting surface, shall intersect that surface actually within the mass of the structure.

If the intersecting surface be imagined to take up an infinite number of different positions, 1, 2, 3, 4, 5, 6, &c., and the intersections with it, *a*, *b*, *c*, *d*, &c., of the directions of all the corresponding resultants be found, then the curved line, *a*, *b*, *c*, *d*, *e*, *f*, joining these points of intersection, may, with propriety, be called the Line of Resistance; the resisting points of the resultant pressures upon the contiguous surfaces lying all in that line. This line can be completely determined by the methods of analysis in respect to a structure of any given geometrical form having its parts in contact by surfaces also of given geometrical forms. And conversely, the form of this line being assumed, and the direction which it shall have through any proposed structure, the geometrical form of that structure may be determined, subject to these conditions; or lastly, certain conditions being assumed, both as it regards the form of the structure and its line of resistance, all that is necessary to the existence of these assumed conditions may be found.

Fig. 11



Let the structure $A\,B\,C\,D$, fig. 11, have for its line of resistance the line PQ. Now, it is clear that if this line cut the surface MN, of any section of the mass in a point N', without the surface of the mass, then the resultant of the

pressures upon the mass $C\ M\ N$, will act through N', and cause this portion of the mass to revolve about the nearest point N, of the intersection of the surface of section $M\ N$, with the surface of the structure. Thus, then, it is a condition of the equilibrium that the line of resistance shall intersect the common surface of contact of each two contiguous portions of the structure, actually within the mass of the structure ; or, in other words, that it shall actually go through each joint of the structure, avoiding none ; this condition being necessary, that no two portions of the structure may revolve on the edges of their common surface of contact.

THE LINE OF PRESSURE.

But, besides the condition that no two parts of the structure should turn upon the edges of their common surfaces of contact, which condition is involved in the determination of the Line of Resistance ; there is a second condition necessary to the stability of the structure—its surfaces of contact must nowhere slip upon one another. That this condition may obtain, the resultant corresponding to each surface of contact must have its direction within certain limits. These limits are defined by the surface of a right cone, having the normal to the common surface of contact (at the above mentioned point of intersection of the resultant) for its axis, and having for its vertical angle, twice that, whose tangent is the co-efficient of friction of the surfaces. If the direction of the resultant be within this cone, the surfaces of contact will not slip upon one another; if it be without it, they will. Thus, then, the direction of the consecutive resultants, in respect to the normal to the point where each intersects its corresponding surface of contact, are to be considered as important elements of the theory. Let, then, a line $A\ B\ C\ D\ E$, fig. 10, be taken, which is the locus of the

consecutive intersections of the resultants aA, bB, cC, dD, &c. The direction of the resultant pressure upon every section is a tangent to this line.

It may, therefore, with propriety, be called the Line of Pressure. Its geometrical form may be determined under the same circumstances as that of the line of resistance. A straight line, cC, drawn from the point c, where the Line of Resistance a, b, c, d, intersects any joint 5, 6, of the structure, so as to touch the Line of Pressure $A\ B\ C\ D$, will determine the direction of the resultant pressure upon that joint; if it lie *within* the cone spoken of, the structure will not slip upon that joint; if it lie *without* it, it will. Thus the whole theory of the equilibrium of any structure is involved in the determination with respect to that structure of these two lines—the Line of Resistance and the Line of Pressure.

One of these lines, the Line of Resistance, determining the point of *application* of the resultant of the pressures upon each of the surfaces of contact of the system; and the other, the Line of Pressure, the *direction* of that resultant.

THE STABILITY OF A STRUCTURE.

It is evident that the degree of the stability of a structure, composed of any number of separate but contiguous solid bodies, depends upon the less or greater degree of approach which the line of resistance makes to the extrados or external face of the structure; for the structure cannot be thrown over until the line of resistance is so deflected as to intersect the extrados. The more remote is its direction from that surface, when free from any extraordinary pressure, the less is therefore the probability that any such pressure will overthrow it. The nearest distance to which the line of resistance approaches the extrados presents itself in the wall and buttresses, commonly at the lowest section of the structure.

It is evidently beneath that point where the line of resistance intersects the lowest section of the structure that the greatest resistance of the foundation should be opposed. If that point be firmly supported, no settlement of the structure can take place under the influence of the pressures to which it is ordinarily subjected.*

LINE OF PRESSURES IN AN ARCH.—CONDITION OF STABILITY.

If a straight line be drawn through each bed-joint of the arch-ring, representing the position and direction of the resultant of the pressure at that joint, the straight lines so drawn form a polygon, and each of the angles of that polygon is situated in the line of action of the resultant external forces acting on the arch-stone which lies between the pair of joints to which the contiguous sides of the polygon correspond; so that the polygon is similar to a polygonal frame, loaded at its angles with the forces which act on the arch-stones (their own weight included).

A curve inscribed in that polygon, so as to touch all its sides, is the line of pressure of the arch. The smaller and the more numerous the arch-stones into which the arch-ring is sub-divided, the more nearly does the polygon coincide with the curve; and the curve, or line of pressures, represents an ideal linear arch, which would be balanced under the continuously distributed forces which act on the real arch under consideration. From the near approach of this linear arch to the polygon, whose sides traverse the centres of resistance of the bed-joints, the points where the linear arch cuts those joints, may be taken, without sensible error,

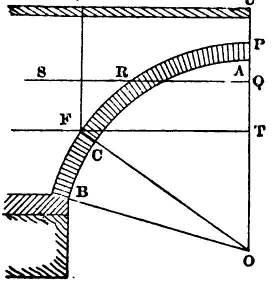
*A practical rule of Vauban, generally adopted in fortifications, brings the point where the line of resistance intersects the base of the wall, to a distance from the vertical to its centre of gravity of 4-9 of the distance from the latter to the external edge of the base.

for the centres of resistance. Now, in order that the stability of the arch may be secure, it is necessary that no joint should tend to open, either at its outer or at its inner edge, and in order that this may be the case, the centre of resistance of each joint should not deviate from the centre of the joint by more than $^1/_6$ of the depth of the joint; that is to say, the centre of resistance should lie within the middle third of the depth of the joint; whence follows this *Theorem: The stability of an arch is secure, if a linear arch, balanced under the forces which act on the real arch, can be drawn within the middle third of the depth of the arch-ring.*

RUPTURE.

In most of the examples of circular arches which occur in practice, the angle of rupture lies between 45° and 55°, so that if the square backing is carried up to that part of the arch which is inclined at an angle of 45° to the horizon, its height will be sufficient at least. It further appears by trial, that the following approximate rule seldom errs by so much as $^1/_{20}$ part, in giving the horizontal thrust of the arch: *The horizontal thrust is nearly equal to the weight, supported between the crown and that part of the soffit whose inclination is* 45°. Thus, in the Fig. 12, let $A\,B\,C$ represent one

Fig. 12



half of a circular arch, O being the centre of the intrados, and OA its radius $= r$; let $OP = r'$, $PU = c$, VU being the horizontal platform. Draw OCF, making the angle $AOC = 45°$ with the vertical; then the horizontal thrust of the arch will be nearly equal to the weight of the mass $ACFVU$, which lies between the joint, CF, and the crown. The point F, is that up to whose level it is advisable to build the backing solid; or, at all events, to bond and joint it in such a manner that it shall be capable of transmitting a horizontal thrust. Draw FT horizontal; then $PT = .7071\ OP$.

DEPTH OF KEY-STONE.

For the depth of the keystone take a mean proportional between the radius of curvature of the intrados at the crown, and a constant whose values are for a single arch .12 foot, for an arch forming one of a series, .17 foot, that is to say in symbols. Depth of key-stone for a single arch, in feet $= \sqrt{(.12 \times \text{radius, at crown})}$. Depth of key-stone for an arch in series, in feet $= \sqrt{(.17 \times \text{radius, at crown})}$.

An abutment in radiating courses, forms, in truth, a continuation of the arch, and is the strongest and most stable kind of abutment where the foundation is firm, and the height from which the arch springs is moderate. In some of the best examples of bridges, the thickness of the abutments ranges from $1/_{8}$ to $1/_{5}$ of the radius of curvature of the arch, at its crown.

PRINCIPLES OF STRENGTH IN ARCHES.

In all arches, whether semi-circular, segmental, gothic, or parabolic, the maximum of strength is obtained when the line Cb, Fig. 13, falls well within the voussoirs. The weakest point in any arch is about midway between the points C

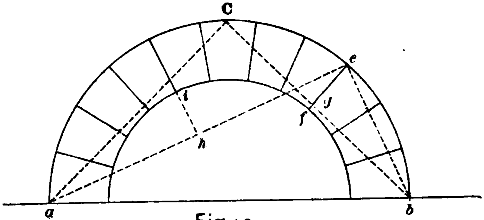


Fig. 13

and *b*. The weight acts in straight lines, and always takes the nearest or most direct course from itself, or from where it is placed, to the ground by which it is ultimately supported. Thus, *Cb* is the line of force. The more an arch is loaded by regular masonry the less it has to bear. In proportion to the length of the lines, *hi* and *fg*, so has the strength of the arch decreased. The gothic form of arch in high wall or building is the best, since it is the form which coincides nearest to the natural arch; (any breach through a wall of masonry takes this form in the upper part of the opening). Arches supported on piers are weakest at the crown. Where there is equal and similar pressure, there should be equal and similar arches and piers to meet it. It is the proportion of the mass of matter of the arch to the weight that is to pass over it, which must regulate the whole.

THE CONDITIONS OF EQUILIBRIUM OF A STRUCTURE

Are the three following: 1st.—That the forces exerted on the whole structure, by external bodies, shall balance each other. The forces to be considered under this head are: 1—The attraction of the earth, that is, the weight of the structure. 2—The external load arising from the pressures exerted against the structure by bodies not forming part of it nor of its foundation; (these two kinds of forces constitute

the gross or total load). 3—The supporting pressures, or resistance of the foundation. These three classes of forces will be spoken of together as the external forces.

2d. That the forces exerted on each piece of the structure shall balance each other. These consist of (1), the weight of the piece, and (2), the external load on it, making together the gross load; and (3), the resistances or forces exerted at the joints between the piece under consideration, and the pieces in contact with it.

3d. That the forces exerted on each of the parts into which each piece of the structure can be conceived to be divided shall balance each other. Suppose an ideal surface to divide any part of any one of the pieces of the structure from the remainder of the piece; the forces which act on the part so considered, are: (1) its weight; and (2), (if it is at the external surface of the piece) the external force applied to it, if any, making together, its gross load; (3), the stress, or force exerted at the ideal surface of division, between the part in question and the other parts of the piece.

STABILITY, STRENGTH AND STIFFNESS.

It is necessary to the permanence of a structure that the three foregoing conditions of equilibrium should be fulfilled; not only under one amount and one mode of distribution of load, but under all the variations of the load, as to amount and mode of distribution, which can occur in the use of the structure.

STABILITY

Consists in the fulfillment of the first and second conditions of equilibrium of a structure, under all variations of the load, within given limits. A structure which is deficient in stability gives way by the displacement of its pieces from

their proper positions. When a structure or one of its parts is flexible, like the chain of a suspension bridge, or in any other way free to move, its stability consists in a tendency to recover its original figure and position after having been disturbed.

STRENGTH

Consists in the fulfillment of the third condition of equilibrium of a structure; for all loads not exceeding prescribed limits, that is to say, the greatest internal stress produced in any part of any piece of the structure by the prescribed greatest load, must be such as the material can bear, not merely without immediate breaking, but without such injury to its texture as might endanger its breaking in the course of time. A piece of a structure may be rendered unfit for its purpose, not merely by being broken, but by being stretched, compressed, bent, twisted, or otherwise strained out of its proper shape. It is necessary, therefore, that each piece of a structure should be of such dimensions that its alteration of figure, under the greatest load applied to it, shall not exceed given limits. This property is called *stiffness*, and is so connected with strength that it is necessary to consider them together.

SUMMARY OF THE PRINCIPLES OF THE BALANCE OF FORCES.

A *Force* is an action between two bodies, either causing or tending to cause change in their relative rest or motion. Equilibrium, or Balance, is the condition of two or more forces, which are so opposed that their combined action on a body produces no change in its rest or motion, and that each force merely *tends* to cause such change without actually causing it. In treatises on statics the word *pressure* is often

used to denote any balanced force, although in the popular sense, that word is used to denote a force of the nature of a thrust or push, distributed over a surface. The relation of a force, to one of the two bodies between which it acts, is determined or made known when the following three things are known respecting it : first, the place or part of the body to which it is applied ; secondly, the direction of its action ; thirdly, its magnitude.

1st. The place of the application of a force to a body may be the whole or part of its internal mass, in which case the force is an attraction or a repulsion, according as it tends to move the bodies between which it acts towards or from each other; or the place of application may be the surface at which two bodies touch each other, or the bounding surface between two parts of the same body; in which case the force is a tension or pull, a thrust or push, or a lateral stress, according to circumstances. Thus, every force has its action distributed over a certain space, either a volume or a surface, and a force concentrated at a single point has no existence. Nevertheless, it is necessary, in treating of the principles of statics, to begin by demonstrating the properties of such ideal forces conceived to be concentrated at single points ; for the conclusions so arrived at respecting single forces (as they may be called) are applicable to the distributed forces which really act in nature.

2d. The *direction* of a force is that of the motion which it tends to produce. A straight line drawn through the point of application of a single force, and along its direction, is the *line of action* of that force.

3d. The *magnitudes* of two forces are equal when, being applied to the same body in opposite directions along the same line of action, they balance each other. A single force may be represented on paper by an arrow-headed straight line, the commencement of the line indicating the point of

application of the force ; the direction of the line, the direction of the force ; and the length of the line, the magnitude of the force, according to an arbitrary scale.

Stress.—The word stress has been adopted as a general term to comprehend various forces which are exerted between contiguous bodies or parts of bodies, and which are distributed over the surface of contact of the masses between which they act. The intensity of a stress is its amount in units of weight, divided by the extent of the surface over which it acts in units of area. The various kinds of stress may be thus classed:

1st. *Thrust*, or *Pressure*, is the force which acts between two contiguous bodies, or parts of bodies, when each pushes the other from itself.

2d. *Pull*, or *Tension*, is the force which acts between two contiguous bodies, or parts of bodies, when each draws the other towards itself. Pressure and tension may be either *normal* or *oblique*, relatively to the surface at which they act.

Shear, or *Tangential Stress*, is the force which acts between two contiguous bodies, or parts of bodies, when each draws the other sideways, in a direction parallel to their surface of contact.

The Angle of Repose is the steepest inclination of a plane to the horizon at which a block of a given substance will remain balanced on it without sliding.

The Co-efficient of Friction of a given pair of surfaces is the *tangent* of an angle, called the *angle of repose*, being the greatest angle which an oblique pressure between the surfaces can make with a perpendicular to them, without making them slide on each other.

EQUILIBRIUM OF ABUTMENTS AND WALLS.

Walls and abutments are usually exposed to two forces:

their own weight, acting in a vertical direction through their centre of gravity, and the pressure occasioned by the extraneous load which they have to sustain; and upon the magnitude and direction of the resultant of these pressures the stability of the structure depends.

They may yield or give way in three different ways, namely: the wall or abutment may separate into two portions, one sliding or slipping upon the other; or, it may similarly separate, and the upper portion turn over about one or other of its edges; or the material of the wall may be crushed by the pressure exceeding its cohesion. Or, in case the wall or abutment itself is too strong to be broken or crushed, it may still yield in any one of the above ways, by either sliding upon the surface of the ground, or turning over upon one of its lower edges, or from the ground yielding under the pressure. For example, let *A B C D*, Figs. 14 and 15, repre-

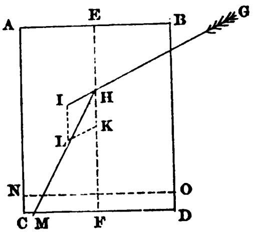


Fig. 14

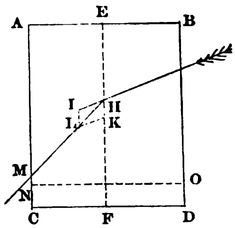


Fig. 15

sent two walls, each sustaining a pressure acting in the direction *G I*. Let *E F* be the vertical line passing through the centre of gravity; *H* the point at which it is intersected by the direction of the pressure; also, let *H K* represent the the weight of the wall, and *H I* the amount of the pressure; then the diagonal, *H L*, will represent their resultant, acting in the direction *H M*.

Now let *N O*, Fig. 14, be a joint in the masonry of the

wall, then, (neglecting the adhesion of the cement,) if the angle *MHF*, which the resultant makes with the perpendicular, be greater than the limiting angle of resistance, the upper portion of the wall, *A B N O*, will slide upon the lower portion *N O C D*; and if the adhesion of the cement, (being now taken into account,) is sufficient to prevent the wall separating at *NO*, then will the whole wall, *ABCD*, slide bodily upon the ground, in contact with its base, *CD*; if, however, the angle which the resultant, *H M*, makes with the perpendicular to the joints, is less than the limiting angle of resistance, the wall cannot yield by the sliding of its parts upon each other; and the stability of the wall or abutment will be greatest in this respect, when the resultant, *HM*, is perpendicular to all the joints, and also to its base, *C D*. If the resultant, *HM*, instead of falling within the base of the wall, cuts the side, *AC*, as in Fig. 15, then will the wall separate at the nearest joint, *NO*; and the upper portion will be overthrown, turning upon its edge at *N*; should, however, the adhesion of the cement be sufficient to prevent the separation of any of the joints, then will the whole wall, *ABCD*, be thrown over bodily, turning on its lower edge, *C*. The wall, however, cannot be overthown, so long as the resultant keep within its substance and cuts the base, *C D*; and its stability in this respect will be greatest when the resultant passes through the centre of its base, *CD*.

In the construction of a bridge, the most important point is to obtain an unyielding foundation for the piers and abutments, and if this can be secured, the engineer may, with safety, adopt bold proportions for the arches of his bridge. But, in a situation in which the piers would be likely to settle to any extent, every precaution should be taken to increase the stability of the arches. It is a matter which may reasonably excite surprise, that engineers should so universally construct the piers of their bridges with solid masonry,

since a very little consideration would suffice to show that such a mode of construction is usually the worst which could be adopted, especially where the ground beneath the piers is of a yielding nature. The real office which the pier of an arch is intended to perform is merely to support the arch, to receive its weight, and to transmit it to the foundation; and it performs this in the most perfect manner when it adds to that weight in the least degree. In most cases, however, the weight of the pier itself is equal to about half that of the superincumbent arch, so that the weight which the foundations have to carry is half as much again as the real weight of the bridge. In the construction of the piers of a bridge the points which ought to be attended to are as follows, namely: that the substance of the pier shall be sufficient to enable it to sustain, without injury, the vertical pressure of the arch and its load, as well as that of the water and any incidental force to which it might, under extraordinary circumstances, be liable to be exposed; and that its base should be of such dimensions that the pressure arising from its own weight, and that which is insistent upon it, may be distributed over a sufficiently large area of ground. Now, so long as these two conditions are fulfilled, it is sufficient, and any additional substance given to the pier is clearly so much additional load thrown upon the foundations, and is positively detrimental to the stability and security of the structure. The foregoing remarks apply with equal force in the case of abutments as in that of piers, the usual practice in the construction of which has been to form a solid mass of masonry, the weight of which materially assists the thrust of the arch in producing settlement by the compression of the ground upon which it rests. It is obvious that the real use of an abutment to an arch is nothing more than to extend the surface upon which it rests, and from which it derives support, without, at the same time, materially increas-

ing its pressure, and so, by reducing the load on any given area, to increase the stability of the structure; whereas, it would be found, in the majority of cases, that the pressure upon every square foot of surface at the springing, is less than that which the thrust of the arch and the additional weight of the abutment, together, occasion on the foundation upon which they rest.

In building a structure, the weight of which is considerable, upon any kind of substratum (excepting only rock), some amount of sinking or settlement, from the compression of the ground, will almost always be found to take place; and as it is very desirable, in the case of a bridge, that the settlement of the piers and abutments, if any, should take place previous to the construction of the arch, the piers and abutments when built up to the springing course, should be loaded with a weight equal at least to that of the arch which they afterwards carry, and in this state they should be left, if possible, for some months, during which period the water should be admitted into the interior of the coffer dams, so that the piers may be brought, as nearly as possible, into the same condition as that in which they would be when the bridge was completed; so that if the ground is disposed to yield under the joint influence of the water and the load, it may do so before the construction of the arches is commenced. Previous to the piers being loaded, and at regular intervals afterwards, careful levels should be taken to ascertain whether any settlement has occurred, and as soon as it has been found, by means of these observations, that all subsidence has ceased, and not until then, the arches should be commenced. The loading of the piers should be gradually removed as the arches progress, in such manner that the weight upon the piers may be maintained as nearly uniform as possible. It is requisite that the centre of an arch, of any size, should be constructed with the greatest possible care,

and in such manner that the weight of the arch-stones may not alter its form;—a point very difficult to be secured with a material so elastic as timber, and where the load is at first thrown only on a small portion of the framing. In cases where this has not been sufficiently attended to, it has been found requisite to place a load upon the middle of the centers, to counteract their tendency to rise at that point, occasioned by the depression of their haunches under the weight of the arch-stones.

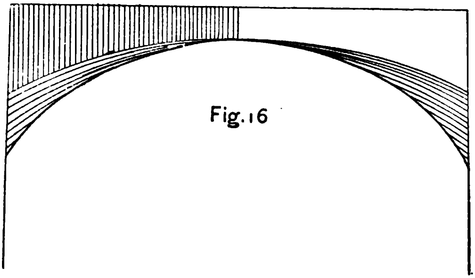


Fig. 16

The elevation, Fig. 16, of the bridge constructed by Telford, over the Severn, at Gloucester, has been introduced for the purpose of pointing out a peculiarity in the form of its soffit, first suggested by Perronet, which consists in making the curve of the intrados of the arch flatter at the face than in the middle of the arch, so as to form a kind of splay on each side, commencing at the haunches and dying away at the crown where the two curves are made to coincide, and at which point alone the soffit of the arch is straight on the transverse section. In the example which we have selected, the form of the arch in the centre is an ellipse, while the line of the intrados on each of the external faces of the bridge forms a flat segment of a circle. We have already explained, while treating of the stability of arches, that when the crown of an arch sinks, the tendency of the arch-

stones, near the crown, is to turn upon their outer edges, and of those near the haunches, upon their inner edges; the effect of which is frequently seen in the opening of the joints at the back of the arch at the haunches, and on the soffit of the arch near the crown, pieces being frequently splintered off from the opposite edges of the joints in consequence of this tendency to turn about them. Now, in this bridge, this tendency of the joints to open was guarded against by the insertion of thin plates of lead between the arch-stones on each side, from the springing, up as far as that point in the arch where the line of pressure passes through the centre of the stones, which, in this case, was assumed to be about one third of the arch; and further, by two wedges of lead being laid under the springing course, which were an inch and a half in thickness on the face of the arch, and ran out to nothing at the back. By these means, as the arch settled, the lead being of a yielding nature, became slightly compressed, and caused the pressure to be more equally distributed over the surface of the joints. The following method was also adopted of setting the key-stones, by which the joints near the crown of the arch were somewhat compressed previous to the centres being struck, namely: three thin strips of lead were placed on the sides of each of the stones composing the last course on each side of the key stones, which latter, having been smeared with white lead and oil, were forced down into their places, the strips of lead serving as slides to prevent the stones rubbing against each other.

BUTTRESSES AND RETAINING WALLS.

Stability of blocks of masonry and brickwork in general depends on the following conditions, viz.: that of stability of position, which requires that the structure shall not give way by overturning; and that of stability of friction, which

requires that it shall not give way by the sliding of one course upon another; and these two conditions ought to be fulfilled at the bed-joint of each course.

The following are the most convenient ways of expressing these conditions by means of formulæ suitable for calculation:

1st. Stability of position is insured, when the moment of the force tending to overturn the mass above a bed-joint, does not exceed the moment of stability of the mass of masonry above that joint. To express the moment of stability at a given bed-joint symbolically, it is necessary in the first place to determine the greatest distance to which the "centre of pressure," or "of resistance," at that bed-joint may deviate from the middle of the bed, without endangering the stability of the structure. Let q denote the greatest safe ratio of the deviation to the thickness of the masonry at the given bed-joint. In flying buttresses and piers, and abutments of arches and of frames, it is in general advisable to limit q to the rule, viz.: *that there shall be no tension at any point of the bed;* the pressure being supposed to be an uniformly varying stress. The value of q of most common occurrence is that for solid rectangular structures, viz.: $q = {}^1/_6$. In retaining walls for sustaining the pressure of earth or of water, the following are average values of q, deduced from the dimensions of actual retaining walls. According to the practice of British engineers $q = .375$, nearly. According to the practice of French engineers $q =$ from .3 to .25. The following is a method of determining the greatest value of q for a rectangular structure, consistent with safety from crushing of the material, based on the supposition that the intensity of the pressure diminishes at an uniform ratio from the compressed edge of the bed-joint inwards; that the mortar exerts no appreciable tension, and that consequently the distance of the centre of resistance

from the compressed edge, is one third of the thickness throughout which the pressure is distributed. Let R be the total pressure at the bed-joint, $\left\{\begin{matrix} b \text{ the breadth,} \\ t \text{ the thickness} \end{matrix}\right\}$ of the mass of masonry at that joint in feet, f' the greatest safe pressure in lbs. on the square foot (being about one eighth of the crushing pressure), then $f' = 2\ R \div \left(\frac{3}{2} - 3\,q\right) b\ t$, and therefore $q = {}^1/_2 - \frac{2\ R}{3\,f'\ b\ t}$ (1). The value of q having been fixed, let $r\ t$ denote the distance from the middle point of the bed, to the point where the bed is cut by a vertical line let fall from the centre of gravity of the mass of masonry above it; W the weight of that mass, and j the inclination to the horizon, of a line in the plane of the bed connecting the limiting position of the centre of resistance, with the point directly below the centre of gravity before mentioned. Then the moment of stability is $M = W (q \pm r)\ t\ cos.\ j$ (2), the sign $\pm$ being used according as the centre of resistance and the vertical line through the centre of gravity, lie towards $\left\{\begin{matrix} \text{opposite sides} \\ \text{the same side} \end{matrix}\right\}$ of the middle of the diameter.

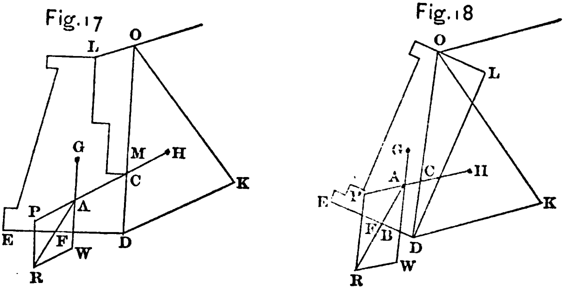
The following is the general expression for the moment, relatively to the limiting position of the centre of resistance of an externally applied force, tending to overturn the mass of masonry above the given bed-joint. Let P denote the magnitude of that force, θ the angle which its direction makes with the horizon, in a direction *contrary* to that of the slope j of the bed, $\left\{\begin{matrix} \chi' \text{ the vertical height} \\ \gamma' \text{ the horizontal distance} \end{matrix}\right\}$ of its point of application from the centre of resistance of the bed; then the perpendicular distance of P from the centre of resistance is $\chi'\ cos.\ \theta - \gamma'\ sin.\ \theta$; and the required moment is given by the following formulæ, which also expresses the

condition that that moment shall not exceed the moment of stability of the masonry: $P(\chi' \cos. \theta - y' \sin. \theta) \leq M.$

2d. Stability of friction is insured when the resultant pressure makes, with a normal or line perpendicular to the bed, an angle not exceeding the angle of repose of the materials.

STABILITY OF RETAINING OR REVETMENT WALLS IN GENERAL.

Figs. 17 and 18 represent vertical sections of retaining walls against which banks of earth abut. In each figure a vertical layer of the masonry and of the earth is supposed



to be considered, whose length is unity. $D\ E$ is the base of the layer of masonry; F the centre of resistance of that base; B a point vertically below G, the centre of gravity of the weight which rests on that base; $\overline{A\ W}$, a line representing that weight; $\overline{A\ P}$, a line representing the thrust of the earth; $\overline{A\ R}$, the diagonal of the parallelogram $A\ P R\ W$, is a line representing the resultant pressure at the base $D\ E$, and cutting that base in the centre of resistance F. In each figure, $D\ O$ is a vertical plane traversing the inner edge, D, of the base of the wall, and cutting the plane of the surface

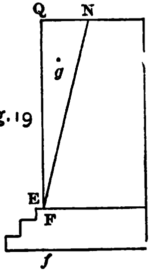
of the bank in O. In Fig. 17, the whole of the wall lies in front of that vertical plane; so that the weight represented by $\overline{AW}$ (or by W simply), which rests on the base, $D\,E$, consists of the weight of the masonry, together with the weight of the mass of earth, if any (represented by $O\,L\,M$), which is vertically above that base, and G is the common centre of gravity of the compound mass of masonry and earth which is situated in front of the plane $O\,D$. In Fig. 18, on the other hand, a part of the masonry represented by $D\,L\,O$ lies *behind* the plane, $O\,D$. If the prism, $D\,L\,O$, consisted of earth, its weight would be supported by the earth beneath it; therefore the earth beneath that prism exerts a pressure vertically upwards sufficient to sustain the weight of a prism of earth of a volume equal to that of the prism of masonry; therefore, the weight represented by $\overline{AW}$ (or by W simply), which rests on the base, $D\,E$, consists of the weight of the masonry in the vertical layer of the wall, *less* the weight of the earth which would fill $D\,L\,O$; and G is the common centre of gravity of the masonry $E\,D\,O$, which lies before the plane $O\,D$, and of the prism $D\,L\,O$, considered to have a heaviness equal to the *excess of the heaviness of masonry above that of earth.* It has been shown that the pressure of the earth against the vertical plane $O\,D$ (which pressure is parallel to the surface of the bank, and represented by $\overline{AP}$ (or by P simply), is equal to the weight of the prism of earth $O\,D\,K$, in which $D\,K$, parallel to the surface of the bank, is equal to the vertical depth, $O\,D$, multiplied by the ratio of the conjugate pressures at a point, $\frac{p'}{p} = \frac{\cos.\,\theta - \sqrt{\cos.^2\,\theta - \cos.^2\,\phi}}{\cos.\,\theta + \sqrt{\cos.^2\,\theta - \cos.^2\,\phi}}$, which ratio depends on the slope θ of the bank, and angle of repose ϕ; and that the resultant of that pressure traverses c at the height $\overline{CD} = \frac{\overline{OD}}{3} = \frac{x}{3}$ above D.

The inclination of the resultant $A\ R$ to the vertical is given by the equation, tang. $< W A R = \frac{P \cos.\ \theta}{W + P \sin.\ \theta}$. When the base $D\ E$ is horizontal, this should not exceed the tangent of the angle of repose. When that base is inclined at the angle j, the condition of frictional stability is thus expressed, $< W A R - j \leq \psi$, ψ being the angle of repose of the foundation of the wall. The object of giving the base of the wall an inclined position is to diminish the obliquity of the pressure upon it, and so to enable the condition of frictional stability to be fulfilled.

STABILITY OF BATTERING-FACED RETAINING WALLS.

In Fig. 19, let $E\ Q$ represent the vertical face of a rectangular wall, suited to sustain the thrust of a given bank,

Fig. 19



and let F be the centre of resistance of the base. Make $\overline{Q\ N} = \overline{3\ E\ F} = 3\ (\frac{1}{2} - q)\ t$; then the centre of gravity g of the triangular prism of masonry, $E\ Q\ N$, will be vertically above the centre of resistance F; therefore if that prism be removed so as to reduce the cross section of the wall to a trapezoid with a battering face, $E\ N$, the position

of the centre of resistance, F, will not be altered, and the wall will still fulfill the condition of stability of position, the thickness, t, being determined as for a rectangular wall. The thickness of the wall at the summit is $(3q - 1/2)\, t$. The tangent $< W A R$ (the inclination of the resultant pressure to the vertical) is increased in the ratio $1/4 + \frac{3q}{2}$: 1; so that it may in some cases be necessary to make the base slope backwards, as in Fig. 18.

STONE MASONRY.—General Principles.

To build the masonry as far as possible in a series of courses perpendicular, as nearly as possible, to the direction of the pressure which they have to bear, and to avoid all long continuous joints parallel to that pressure, by "breaking joint." To use the largest stones for the foundation course. To lay all stones which consist of layers or beds in such a manner that the principal pressure which they have to bear shall act in a direction perpendicular, as nearly as possible, to the direction of the layers. This is called "laying the stone on its natural bed," and is of primary importance to strength and durability. To moisten the surface of dry and porous stones before bedding them, in order that the mortar may not be dried too fast and reduced to powder by the stone absorbing its moisture.

ASHLAR MASONRY

Consists of blocks cut to regular figures, generally rectangular, and built in courses of an uniform depth, which is seldom less than a foot. In order that the stones may not be liable to be broken across, no stone of a soft material, such as the weaker kinds of sand stone and granular lime stone, should have a length greater than three times its depth;

in harder materials the length may be four or five times the depth. The breadth in soft materials may range from $1^1/_2$ times to double the depth ; in hard materials it may be three times the depth. The bed-joints and side-joints are dressed to plain surfaces (and in exceptional cases to curved surfaces). In the case of plain joints, this is done by making an accurate plane chisel-draught all round the edges of the surface to be shaped, and if the stone is large, some additional transverse chisel-draughts in the same plane, and dressing the remainder of the surface by the point, down to the plane of the chisel-draught, which serves as a guide. The accuracy with which this is done is of special importance in the case of bed-joints; for if any part of the surface projects beyond the plane of the chisel-draught, that projecting part will have to bear an undue part of the pressure which will be concentrated upon it ; and the joint, which will gape at the edges, constitutes what is called an *open joint*, which will be wanting in stability. On the other hand, if the surface of the bed is concave, having been dressed down below the plane of the chisel-draught, the pressure is concentrated on the edges of the stone, to the risk of splintering them off. Such joints are said to be *flushed*. They are more difficult of detection after the masonry has been built, than open joints, and are often executed by design in order to give a neat appearance to the face of the building, and therefore their occurrence must be guarded against by careful inspection of the progress of the stone-cutting. *Great smoothness is not desirable in the joints of Ashlar Masonry intended for strength and durability ;* for a moderate degree of roughness adds at once to the *resistance to displacement by sliding*, and to the *adhesion of the mortar.*

The strongest bond in Ashlar Masonry is that in which each course at the face of the building contains a header and a stretcher alternately, the outer end of each header

resting on the middle of a stretcher of the course below, so that rather more than $^1/_2$ of the area of the face consists of ends of headers; but in every case it is advisable that the ends of the headers should not form less than $^1/_4$ of the whole area of the face of the building. In what manner soever the faces of Ashlar stones are dressed, or even should they be "quarry-faced," there ought to be a chisel-draught round the edges of the face, forming sharp and straight edges with the chisel-draught of the beds and joints, in order that the stone may be accurately set.

BLOCK-IN-COURSE MASONRY

Differs from hammer-dressed Ashlar chiefly in being built of smaller stones. The usual depth of the course is from seven to nine inches. The same rules apply to breaking joints, and to the proportions which the lengths and breadths of the stones should bear to their depths, as in Ashlar; and as in Ashlar also, at least one fourth of the face of the building should consist of headers, whose length shall be from three to five times the depth of a course. Block-in-course masonry is used for spandrels and wing walls of bridges, the facing of retaining walls, etc.

In *Coursed-Rubble Masonry*, one-fourth part at least, of the face in each course, should consist of bond stones or headers; each header to be of the entire depth of the course, of a breadth ranging from $1^1/_2$ to double that depth, and of a length extending into the building to from three to five times that depth, as in Ashlar. No side-joints should have an angle with a bed-joint sharper than 60°. A cubic yard of rubble masonry requires, in order to allow for waste, about $1^1/_5$ cubic yards of stone, and $^1/_5$ cubic yard of mortar.

COMMON RUBBLE MASONRY

Differs from coursed-rubble in not being built in courses, but in other respects the same rules are to be observed. The resistance of common rubble to crushing, is not much greater than that of the mortar which it contains; it is therefore not to be used where strength is required, unless built with strong hydraulic mortar.

CONSTRUCTION OF RETAINING WALLS.

The foundation courses of retaining walls may have their width increased beyond the thickness of the walls, by a series of steps in front. The objects of this are at once to distribute the pressure over a greater area than that of any bed-joint in the body of the wall, and to diffuse that pressure more equally by bringing the centre of resistance nearer to the middle of the base than it is in the body of the wall. The body of the wall may be either entirely of brick, or of ashlar backed with brick or with rubble, or of block-in-course backed with rubble, or of coursed rubble built with mortar or built dry.

As the pressure at each bed-joint is concentrated towards the face of the wall, those combinations of masonry in which the larger and more regular stones form the face and sustain the greater part of the pressure, and are backed with an inferior kind of masonry whose use is chiefly to give stability by its weight, are well suited for retaining walls; special care being taken that the back and face are well tied together by long headers, and that the beds of the facing stones extend into the wall to a distance of about as far inwards from the centre of pressure at the base of the wall, as that centre of pressure lies inwards from the face.

Along the base, and in front of a retaining wall, there should run a drain like that at the foot of the slope of a cutting. In order to let water escape from behind the wall, it has small

upright oblong openings through it, which are usually two or three inches broad, and of the depth of a course of masonry, and are distributed at regular distances; an ordinary proportion being one hole to every four square yards of face of wall. The back of a retaining wall should be rough, in order to resist any tendency of the earth to slide upon it. This object is promoted by building the back in steps. When the material at the back of the wall is clean sand or gravel, so that water can pass through it readily and escape by the holes, it is only necessary to ram it in layers. But if the material is retentive of water, like clay, a vertical layer of stones or coarse gravel, at least a foot thick, or a dry stone rubble wall must be placed at the back of the retaining wall, between the earth and masonry, to act as a drain.

When the material at the back of the wall is of a loamy description and liable to be reduced to quicksand or mud by saturation with water, and there are no means of preventing such saturation by efficient drainage, one way of making provision to resist the additional pressure which may arise from such saturation is to calculate the requisite thickness of wall, as if the earth were a fluid, making ϕ (the angle of repose) $= \Theta$ in the formulæ.

LAND TIES FOR RETAINING WALLS.

Retaining walls having to bear a great pressure while they rest on a yielding foundation, may have their stability increased by being tied or anchored by iron rods to vertical or nearly vertical plates of iron imbedded in a firm stratum of earth, at a distance behind the wall sufficient to prevent its being disturbed by the operations of excavation, building, etc., connected with the erection of the wall. The holding power per foot of breadth of a rectangular vertical anchoring plate, the depths of whose upper and lower edges below

the surface are, respectively, χ^1 and χ^2, may be approximately calculated from the following formulæ. Let w^1 be the weight of a cubic foot of the earth, φ its angle of repose, H, the holding power per foot of breadth. Then $H =$
$w^1 \times \frac{(\chi^2)^2 - (\chi^1)^2}{2} \times \frac{4 \sin. \varphi}{\cos.^2 \varphi}$ (1).

The depth of the centre of pressure of the plate below the surface of the ground, is given by the following expression, $^2/_3 \times \frac{(\chi^2)^3 - (\chi^1)^3}{(\chi^2)^2 - (\chi^1)^2}$, and to that centre the tie-rod should be attached. If the retaining wall depends on the tie-rod alone for its security against sliding forward, they should be fastened to plates on the face of the wall in the line of the resultant pressure of the earth behind the wall, that is at one third of the height of the wall above its base. But if the resistance to sliding forward is to be distributed between the foundation and the tie-rods, they are to be placed at a higher level; for example, if half the horizontal thrust is to be borne by the foundation and half by the tie-rods, the latter should be fixed to the wall at two thirds of its height above the base.

TUNNELS.

Having determined upon the exact course of the tunnel, the next point is to arrange the position of the shafts. These are best placed at equal distances, and their frequency should depend upon the time in which it is necessary to complete the work. There is, however, a certain distance in every case which will be more economical than any other, and this will be readily understood if we bear in mind that the cost of the tunnel itself, per foot forward, becomes greater as its distance from the working shaft increases; so that by lessening the distance between the shafts, and increasing their number, we diminish the cost of the tunnel itself. When, however, the shafts are placed too close,

their cost becomes greater than the saving upon the tunnel, and there will therefore in every case be a certain distance, depending upon the relative cost of the tunnels and shafts, at which the whole work (expense thereof) will be a minimum.

There are two methods in ordinary use for sinking the shafts. The first can only be followed when the ground through which it has to be sunk is tolerably firm and free from water; and consists in making an open excavation of the form and dimensions of the shaft, including space for the internal lining of brick or other materials, and to such a depth as the nature of the ground indicates to be safe. A ring or curb of timber is then laid on the bottom of the excavation, previously levelled to receive it. This curb is formed either of one thickness with lapped joints, or in two thicknesses breaking joints, securely bolted together as shown at *A A*, Figs. 20 and 21. The thickness of the curb

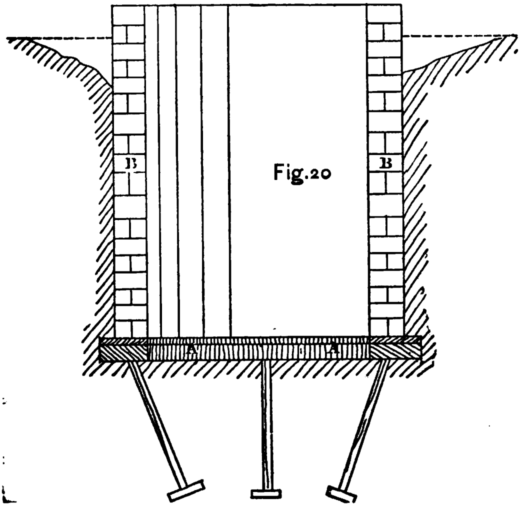
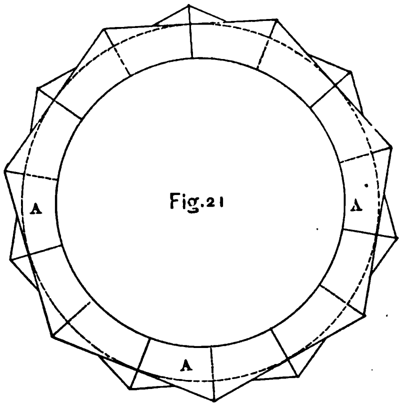


Fig.20



should depend upon the dimensions of the shaft, being in no case less than 3 inches; its internal diameter should be the same as that of the shaft, and its breadth may be made greater, as shown in the figure, so as to project into the ground and assist in supporting the structure. As the curb becomes a part of the permanent work, it should be of oak or elm timber of the best quality. The curb being placed, the wall or lining (*B B*) of the shaft should be proceeded with, especial care being taken to ram in the ground firmly on the outer side so as to leave no space or vacuity; indeed, it is impossible in all operations in tunnels and other subterraneous works to pay too much attention to prevent the slightest vacuity between the work and the ground; but on the contrary, whenever the ground is at all loose or disposed to move, every inch of surface should be well supported and well strutted against, so as to maintain an active pressure at all times against it. As soon as the brick work forming the lining has been carried up to the level of the ground, and the earth securely rammed in behind it, the excavation for a second length may be proceeded with. This, however, must be done with caution, so as not to endanger the stability of

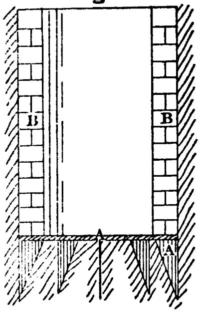
the portion already built, by undermining its foundation. We must first carry down the excavation in the centre of the interior of the shaft, leaving sufficient ground under the curb safely to support it. We may now cautiously remove the ground from under the curb at four opposite points, leaving the intermediate ground to form piers for its support. The spaces or recesses thus excavated, afford the means of introducing shores or props for the temporary support of the curb, while the remainder of the ground is being removed. These props should be placed in an inclined position, as shown in fig. 20, so as not to be in the way of the second curb; they should be spiked to the upper curb to secure them from slipping out of place, and should rest at their lower extremity upon a broad sole piece, to prevent their sinking into the ground. The props having been introduced, the remainder of the ground may be removed; a second curb similar in every respect to the former, laid at the bottom of the excavation, and the lining of brick work proceeded with in the spaces between the timber struts. Upon the brick work being brought up to the under side of the first curb, great care should be taken in perfectly filling up the space, so that the curb may have a firm and secure bed upon the brick work below it.

The props or struts may then be removed and the brick work completed in the spaces which they had occupied. The excavation should be again proceeded with, and the various operations already described repeated, until the shaft has attained the required depth. The mode of building shafts, which has just been described, is technically termed underpinning.

The second method is frequently employed in sinking wells, and must always be adopted when the soil is too loose or full of water to allow of an open excavation being made with safety. It consists in forming the curb as shown at

A A, Fig. 22, with a sharp edge or rim, instead of having a broad flat surface, as in the former case. Upon this curb

Fig. 22



the brick work of the shaft is to be built as before, until carried up to the level of the surface. The excavation within the shaft is then to be proceeded with, the whole of the ground being in this case removed from under the curb, which being thus left without support and being loaded with the weight of the brick work upon it, will gradually descend; and thus, as the excavation is carried down, the curb will follow, and as it sinks the wall must be carried up so as to maintain its level with the surface of the ground. The principal care required in this mode of sinking shafts is to avoid one side of the curb descending more rapidly than the opposite one, by which the shaft would be thrown out of the perpendicular, and so much resistance occasioned as possibly to prevent its further descent. By a little management, however, in the removal of the ground from beneath the curb, this may be usually avoided, and when earth-bound, the shaft may frequently be set free again by pouring water around it, so as to soften the ground on the outer side.

A very good precaution against a shaft becoming earth-bound is to build it slightly tapering upwards; this tapering

should not be too considerable, otherwise the space left around it by the descent of the shaft would be sufficient to loosen the surrounding earth. The brick shaft having, by one or other of these means, been carried down to within a few feet of the top of the intended tunnel, the excavation should then be cautiously proceeded with, the sides being secured with timber framing and planks, until carried below the level of the bottom of the tunnel.

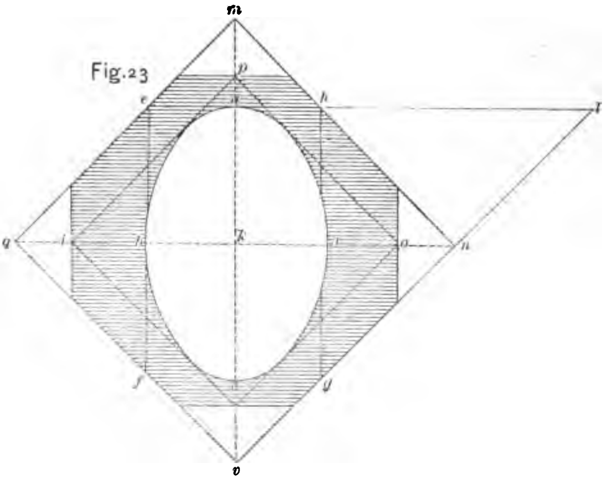
Particular care should be taken that no movement in the ground takes place, because the difficulty of forming the tunnel would be greatly increased if the ground through which it had to be formed had been previously disturbed. Previously to carrying down the excavation below the brick work of the shaft some means must be adopted for its support, as the mere friction of the ground against its exterior surface would not be sufficient to sustain its weight. It is therefore either necessary to support it by introducing timbers underneath it, or to suspend it by rods secured to timbers resting on the surface of the ground above. A small drift-way or heading should now be commenced about the level of the bottom of the tunnel, and having a sufficient inclination given to it to enable any water met with to drain into the bottom of the shaft, which thus becomes a well for the drainage of the works, and from which the water may easily be removed. To ensure the brick work of the tunnel being true in form, curved templates are used for the invert and sides, while the upper portion is turned upon a centre similar to those employed for turning the arches of bridges.

As the brick work proceeds the bars and polings must be carefully removed, and any vacuity thus left must be filled with earth well rammed in, so as to prevent any settlement of the ground, which would occasion unequal strains upon the body of the tunnel. As in most strata some amount of

settlement will take place in the superincumbent ground before the brick work can be got in, the timber and polings should be placed a few inches above the top of the tunnel. As soon as a length of brick work has been got in on each side of the shaft, the temporary timber work of the lower portion of the shaft should be carefully removed, the ground excavated to the true form of the tunnel, and the brick work introduced, being securely bonded with, and connected to, that already built on either side, and the brick work of the shaft being properly carried down to meet that of the tunnel. When the faces of two opposite workings approach within a short distance of each other, great caution is necessary to avoid the thin partition of ground being disturbed. When sandy or other loose strata containing large quantities of water are met with, peculiar precautions must be taken to prevent the loose ground being washed in with the water, which would occasion cavities to be left in the surrounding ground. A simple and effectual mode is to thrust straw into an opening from whence muddy water is found to proceed.

TO CONSTRUCT AN EGG-SHAPED TUNNEL.

The dimensions of a hen's egg are $2^1/_8$ inches for the greater axis, and $1^5/_8$ inches for the smaller axis, or the major is to the minor axis as 17 to 13. Having laid down the axis major, *a c*, at $2^1/_8$ inches, and the axis minor, *b d*, at $1^5/_8$ inches, the ellipse, *a b d c*, was described by taking $^2/_3$ of the axis major for the radius of the sides, and the remaining $^1/_3$ for the radius of the ends. These two segments of circles coincided exactly, which was not the case with segments of dissimilar radii. Let *a b c d* be the ellipse described from the centres of two circles, instead of two foci, making the dimensions proportionate to the natural size of the egg selected; then *a c* is the axis major, and *b d*



bisecting $a\ c$ at right angles, at k, is the axis minor. At the points b and d, draw the straight lines $e\,f$ and $h\ g$ parallel to $a\ c$, and at the points a and c, draw the straight lines $e\ h$ and $f\ g$ parallel to $b\ d$. Produce $a\ c$ indefinitely both ways, and let $a\ m$ equal $a\ e$ or $a\ h$, and $c\ v$ equal $c\,f$ or $c\ g$. Join $e\ m$, $m\ h$, $f\ v$, and $v\ g$. Produce likewise $b\ d$ indefinitely both ways, and let $d\ n$ equal $d\ h$ or $d\ g$, and $b\ q$ equal $b\,f$ or $b\ e$. Join $h\ n$, $n\ g$, $f\ q$, and $q\ e$. Now, in the triangle $a\ e\ m$, the angle $a\ e\ m$, equals the angle, $a\ m\ e$; and the angle, $e\ a\ m$, is a right angle, therefore the angle, $a\ e\ m$, is $=$ 45°.

In like manner it may be shown that the several angles, $a\ h\ m$, $d\ h\ n$, and $d\ g\ n = 45°$; also, the same may be shown in the triangles, $g\ v\ f$ and $f\ q\ e$. It having been shown that masonry forms a natural arch at an angle of 45°, the law with regard to the pressure of solid earth must be similar, and the weight to be borne on the arch at a equals the angle, $e\ m\ h$, in perpendicular pressure. As re-

spects lateral pressure, it is known that a bank of earth will just support itself when inclined at an angle of 45°. Produce *e h* and *g n* until they meet *l*. Let *g n l* be a plane inclined 45°, and let *g h l* be a mass of earth resting upon this inclined plane, and consequently pressing against *h g*. If the straight line, *l g*, represents the force of this body of earth, it may be resolved into two straight lines, *l h* and *h g*; but *h g* is parallel to the side, therefore *l h* is the force which alone acts against the side. In the two triangles, *h g n* and *h l n*, it may be easily proved that $l\,h = h\,g$, and the triangle, $h\,g\,n = h\,n\,l$; therefore, we have the triangle, *h n g*, representing the proportion of earth out of the whole body contained in the triangle, *h l g*, which alone presses against the side, *h g*. Now $a\,m = a\,e$, or equals the half of *b d*, the axis minor; and $d\,n = d\,h$, or equals the half of *a c*, the axis major; therefore, the triangles, *e m h* and *h n g*, are to each other in the same ratio; that is, the pressure of earth at *a* is to the pressure of earth at *d*, as the axis minor is to the axis major. The same may be shown of the pressure at *b* and *c*. Just without the ellipse, draw the straight line, *p o* parallel to *m n*, and consequently cutting *a m* and *d n* proportionately, in the points *p* and *o*; that is, *a p* is to *d o*, as the axis minor is to the axis major, or as the weight of the earth in the triangle, *e m h*, is to the weight of the earth in the triangle, *h n g*. Let *a p* be the thickness of the masonry at *a*, and *d o* the thickness of the masonry at *d*. We have then the straight line, *p o*, lying within the masonry.

Since the masonry surrounding *d c b*, which is represented in the diagram by the shaded part, rests on the solid earth as the foundation, the remaining part, or the arch, *b p d*, need only to be considered. With regard then to this part of the arch, we have at *i* and *o*, two immovable buttresses in the side earth, with the straight lines, *p i* and *p o* lying within the masonry; therefore the tunnel will bear any

weight on *p*. Again, the masonry at *p* is immovable upward from the resistance of the solid earth above; therefore the arch at *o* is capable of supporting any pressure of the side earth, should it be disposed to slip in. The same may be shown of the points *e f* and *g h*, in consequence of the straight lines, *e h*, *h g*, *g f* and *f e* being within the masonry. A tunnel constructed of this form and masonry will support itself against any pressure.

QUARRYING AND BLASTING.

Two leading errors are committed by quarrymen, to wit: Selecting an injudicious position for the charge, by which the action of the powder is exerted in the direction of the opening where it is introduced, and the adopting as a rule for the several charges to fill a *certain number of inches of the hole bored* (usually $^1/_3$ of its depth), instead of employing given weights *adapted to the lines of least resistance. The line of least resistance* is that line by which the explosion of powder will find the least opposition to its vent in the air. This need not necessarily be the shortest line to the surface, as for instance, a long line in earth may from the same charge afford less resistance than a short line in rock.

Supposing the matter in which the explosion is to take place to be of uniform consistence in every direction, charges of powder to produce similar proportionate results ought to be as the *cubes of the lines of least resistance*: thus, if 4 oz. of powder would have a given effect upon a solid piece of rock 2 ft. thick to the surface, it ought to require $13^1/_2$ oz. to produce the same effect upon a piece of rock 3 ft. thick, or,

Cube of 2 ft. line of least resistance.	Charge of Powder.	Cube of 3 ft.	
as 8	is to 4	so is 27	to $13^1/_2$.

The line *a b*, Fig. 24, represents the line of least resistance.

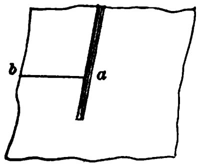
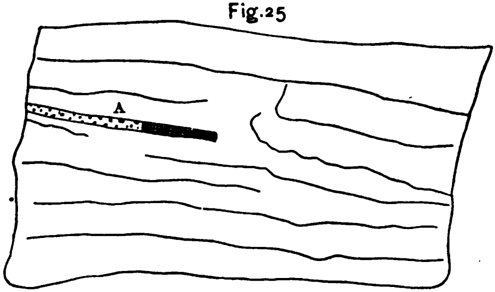


Fig. 24

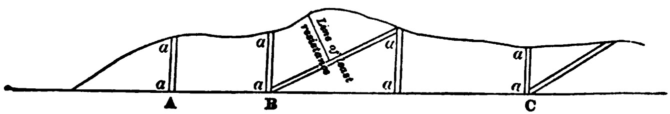
When the rock is stratified, and in close parallel beds and seams, the holes should be bored in the direction of the joints, and the powder laid along them as at *A*, Fig. 25,

Fig. 25

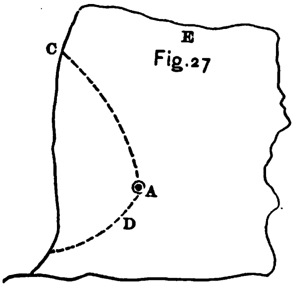


which will have much more effect in lifting large masses than if placed across the grain. Powder is ill applied when the explosion takes place in the same line as the bore. For example, suppose ledges of rock require to be cleared away to a certain level for a road, navigation, or other object; instead of boring holes, *a a*, *a a*, Fig. 26, the effect would be

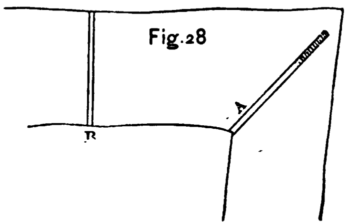
Fig. 26



far better by inclining holes, *A B C*. You thus obtain a line of least resistance in a different direction from that of the hole bored. Where there is a high face of rock, a system of undermining may be advantageously employed. Thus, a blast at *A*, Fig. 27, would make an opening easy



from *C* to *D*, and the mass *E*, if not shaken, as it probably would be so as to be worked on with bars and wedges, would be brought down by slight subsequent blasts. The worst situation for a charge of powder is a re-entering angle as at *A*, Fig. 28. The rock exerts such pressure all



around it that very little effect is had. *B* is very little better.

The desideratum in tamping is to obtain the greatest possible resistance over the charge of powder. Clay is best for tamping material, and broken bricks is next. Rock that

is too hard to be split with the pick, crowbar or hammer, and not so hard as to require blasting, can be quarried in blocks by cutting grooves or boring holes in the upper surface of the bed, inserting blunt steel wedges in them, and driving those with a hammer until a block splits off from the layer. The process of blasting with powder may be be divided into *small blasts* and *great blasts.*

In a *small blast* the explosion of the powder splits and loosens a mass of rock whose volume is approximately proportional to the *cube of the line of least resistance;* that is, in general, of the shortest distance from the charge to the surface of the rock, and may be roughly estimated at *twice* that cube, but this proportion varies very much in different cases. The proportion of the *weight of rock loosened, to the weight of powder exploded,* ranges from 7,000 to 1 to 14,000 to 1; and may be taken on an average at 10,000 to 1. The ordinary rule for the weight of powder in small blasts is, powder, in lbs., $= \left(\frac{\textit{line of least resistance}}{32}\right)^3$.

A test of the strength of blasting powder is, that $^1/_8$ lb. of it, being fixed in an 8 inch mortar, elevated at an angle of 45°, should throw a 68 lb. ball to a distance of 240 feet. 1 lb. of powder in a loose state occupies about 30 cubic inches. 30 cubic inches are equal to 38.2 cylindrical inches, and that is the length of hole, 1 inch in diameter, required to hold one pound of powder. A blast acts *most* efficiently when the line of least resistance (being, in sound rock of uniform strength, the shortest line from the charge to the surface), is perpendicular to the axis of the bore hole. It acts *least* efficiently when the line of least resistance is the axis of the bore hole itself. It is not always possible to jump a hole perpendicular to the intended line of resistance, but the hole should always be made to form as great an angle with that line as possible.

A *great blast* is made by excavating a vertical shaft, or a horizontal heading in the mass of rock, which should turn at right angles at least once, on its way to the powder chamber at its end, in order that the tamping may not be blown out. Such shafts and headings, vary from $3^1/_2$ feet square to $3^1/_2$ feet by 5 feet, and the labor required to make them varies from two to six days' work of a miner per lineal foot.

The mine being swept out and its floor covered with a matting of old sacks, the gunpowder is placed in the chamber in a pine box, whose size is regulated by the fact that 1 lb. of powder fills about 30 cubic inches. A small quantity of finer powder in a bag forms the bursting charge, and is traversed by a fine platinum wire connecting a pair of copper conducting wires with each other. These are coated with India rubber or otherwise insulated, and protected by being placed in a groove in a wooden box. The entrance of the chamber is closed with a wall of turf, and the rest of the mine "tamped," by being built up either with rubble masonry or with a mixture of stones and clay. When the workmen have removed to a safe distance the conducting wires are connected with the opposite ends of a galvanic battery, when the electric current raises the platinum to a white heat and fires the charge. When one charge only is to be fired, a safety fuse may be used. According to Sim, the chamber of the mine should be so placed that the line of least resistance may be about two thirds of the height of the rock to be loosened. In great blasts the proportion of the weight of the rock loosened to that of the powder exploded ranges from 4,500: 1, to 13,000: 1, and averages about 6,500: 1. The ratio of the number of lbs. of powder to the cube of the number of feet in the line of least resistance ranges from 1:32 to 1:10, but the best mode of fixing the quantity of powder is to estimate roughly the weight of the mass of rock which is likely to be loosened,

and use from one half to one third of a pound of powder for each ton of rock. In choosing the positions of bores and mines for blasting, regard should be had to the natural veins and fissures of the rock as means of facilitating its detachment from its bed.

STRUCTURAL CHARACTER OF STONES.

Considered in the light of materials for building, the geological position of rocks has but little connection with their properties as building materials. As a general rule, the more ancient rocks are the stronger and the more durable, but to this there are many exceptions.

The properties or characters of rocks, which are of most importance in an engineering point of view, are of two kinds—the structural and the chemical. With respect to the structural character of their large masses, rocks may be divided into two classes: 1st—The unstratified; 2d—The stratified; according as they do not or do consist of flat layers.

The UNSTRATIFIED ROCKS are believed to have become solid more or less slowly, and under a greater or less pressure from a melted state. They are for the most part, hard, compact, strong, and durable. It is in general obvious that the great masses of unstratified rocks are built, as it were, of blocks, which separate from each other when the rock decays. In granite, for example, those blocks are oblique hexahedrons; in other words, rhomboidal prisms, sometimes of enormous size. In basalt, they are regular hexagonal or pentagonal prisms, built up into columns. In trap, they are irregular prisms, sometimes approximating imperfectly to the columnar form of basalt. In many cases the further progress of decay rounds off the corners and edges of the blocks, and converts them into boulders, which show a tendency to break up into concentric oval layers. In all cut-

ting, quarrying, and blasting of unstratified rocks the work is much facilitated by taking advantage of the natural joints between the blocks, at which the rock is more easily divided than elsewhere. In their more minute structure, the unstratified rocks present, for the most part, an aggregate of crystalline grains, firmly adhering together. In granite and syenite these crystals are comparatively large and conspicuous; in trap, they are much smaller and less distinct.

STRATIFIED ROCKS consist of a series of parallel layers, evidently deposited from water, and originally horizontal, although in most cases they have become more or less inclined or curved by the action of disturbing forces. It is easier to divide them at the planes of division between those layers than elsewhere. They are traversed by veins or cracks, sometimes empty, sometimes containing crystals, sometimes filled with "dykes," or masses of unstratified rocks. It is in the immediate neighborhood of masses of unstratified rock that the stratified rocks show the greatest effects of the action of disturbing forces, in the inclination, curvature, and distortion of their layers. In such positions, too, they often appear to have had their structure altered by heat and intense pressure, and to have been rendered harder and more compact. Besides its principal layers or strata, a mass of stratified rock is in general capable of division into thinner layers; and although the surfaces of divisions of the thinner layers are often parallel to those of the strata, they are also often oblique or even perpendicular to them. This constitutes a laminated structure. Laminated stones resist pressure more strongly in a direction *perpendicular* to their laminæ than parallel to them; they are more tenacious in a direction *parallel* to their laminæ than perpendicular to them; and they are more durable with the edges than with the sides of their laminæ exposed to the air; and therefore

in building they should be placed with their laminæ, or "beds," perpendicular, or nearly so, to the direction of greatest pressure, and with the edges of these laminæ at the face of the wall. In the more minute structure of stratified rocks the following varieties are distinguished: (1) The *compact crystalline* structure, as in quartz rock and marble. This is accompanied by great strength and durability. (2) The *slaty* structure, where the rock, which is usually compact, can be split into innumerable thin layers, often inclined to the stratification. This structure is considered to have arisen from intense pressure in a direction perpendicular to the layers. Some of the stones in which it occurs, as hard clay-slate and horne-blende slate, are amongst the strongest and most durable known. (3) The *granular crystalline* structure, in which crystalline grains either adhere firmly together, as in gneiss, or are cemented together into one mass by some other material, as in sandstone. This is accompanied by various degrees of compactness, porosity, strength, and durability, from the highest to the lowest, passing at the lowest extreme into sandstone. (4) The *compact granular* structure, where the grains are too small to be visible, and seem to form a continuous mass, as in blue limestone. This structure is usually accompanied with considerable strength and durability. It passes by gradations, on the one hand into the compact crystalline structure (1), and in the other into (5) the *porous granular* structure, in which the grains are not crystalline, and are often, if not always, minute shells cemented together as in oölite. The porosity of rock having this structure varies much, and so also do the strength and durability, which are seldom very high. In these respects the lowest example is soft chalk. The *fracture*, or appearance of the broken surface of a stone, is one of the means of showing its structural character. The following are examples: The *even* fracture, when the surfaces

of division are planes in definite positions, is characteristic of a crystalline structure. The *uneven* fracture, when the broken surface presents sharp projections is characteristic of a granular structure. The *slaty* fracture is even for planes of division parallel to the lamination, and uneven for other directions of divisions. The *conchoidal* fracture presents smooth concave and convex surfaces, and is charateristic of a hard and compact structure. The *earthy* fracture leaves a rough, dull surface, and indicates softness and brittleness.

Sandstone is a stratified rock, consisting of grains of sand, that is, small crystals of quartz cemented together by a material which is usually a compound of silica, alumina and lime. In the strongest and most durable sandstone the cementing material is nearly pure silica ; the weakest and least durable is that in which the cement contains much alumina, and resembles soft feldspar or claystone. When there is much lime in the cementing matter of sandstone it decays rapidly in the atmosphere of the sea coast, and in that of towns where much coal is burned; in the former case the lime is dissolved by muriatic acid; in the latter by sulphuric acid.

Calciferous sandstones, as those containing much lime are called, pass by insensible degrees into sandy limestones. The appearance of strong and durable sandstone is characterized by sharpness of the grains, smallness of the quantity of cementing material, and a clear, shining and translucent appearance on a newly broken surface. Rounded grains, and a dull, mealy surface characterize soft and perishable sandstone.

The best sandstone lies in thick strata, from which it can be cut in blocks that show very faint traces of stratification; that which is easily split into thin layers is weaker. Sandstone is found in every geological formation above the primary rocks, amongst which its place is supplied by horn-

stone and quartz rock. The best kinds, on the whole, are those which belong to the coal formation; but they sometimes have their strength impaired by being divided into layers by extremely thin laminæ of coal.

The colors of sandstone are white, yellowish-red, and red, the latter colors being produced by the presence of peroxide of iron in the cementing material. Crystals of sulphuret of iron are sometimes imbedded in it; when exposed to air and moisture they decompose and cause disintegration of the stone. They are easily recognized by their yellow or yellowish-gray color and metallic lustre. Sandstone is, in general, porous and capable of absorbing much water; but it is comparatively little injured by moisture, unless when built with its layers set on edge, in which case the expansion of water in freezing between the layers makes them split or scale off from the face of the stone. When it is built on its "natural bed," any water which may penetrate between the edges of the layers has room readily to expand or escape. The better kinds of sandstone are the most generally useful of building stones, being strong and lasting, and at the same time easily cut, sawn, and dressed in every way, and fit alike for every purpose of masonry.

Calcareous Stones are those in which carbonate of lime predominates. They effervesce with the dilute mineral acids, which combine with the lime and set free carbonic acid gas. Sulphuric acid forms an insoluble compound with the lime. By the action of intense heat the carbonic acid is expelled in the gaseous form, and the lime left in its caustic or alkaline state, when it is called *quicklime*. The durability of calcareous stones depends on their compactness, those which are porous being disintegrated by the freezing of water, and by the chemical action of an acid atmosphere.

Compact Limestone consists of carbonate of lime, either pure or mixed with sand and clay. It varies in hardness

and compactness, sometimes approaching to the condition of marble, sometimes to that of granular limestone. It is very useful as a building stone and is durable in proportion to its compactness.

STRENGTH OF STONES.

Amongst stones of the same kind that which has the greatest heaviness is almost invariably the strongest. Fairburn's experiments show that the resistance of strong sandstone to crushing in a direction parallel to the layers is only six-sevenths of the resistance to crushing in a direction perpendicular to the layers. The hardest stones alone give way to crushing at once, without previous warning; all others begin to crack or split under a load less than that which finally crushes them, in a proportion which ranges from a fraction little less than unity in the harder stones, down to about one-half in the softest. The mode in which stone gives way to a crushing load is in general by *shearing*.

When any building of importance is projected, the best course is not to trust to books for information as to the strength of the stone to be used, but to test it by special experiments by the aid of a hydraulic press. The factor of safety in structures of stone should not be less than *eight*, in order to provide for variations in the strength of the material, as well as for other contingencies. The only sure test, however, of the durability of any kind of stone is *experience*, and the engineer who proposes to use stone from a particular stratum in a particular locality, in any important structure, should carefully examine buildings in which that stone has been already used, especially those of old date.

ANALYSIS OF LIMESTONES AND CEMENT STONES.

Stones containing carbonate of lime, in combination and mixture with other minerals, are the most abundant and

useful source of the cementing materials used in masonry. The following are their principal constituents, with their chemical equivalents: Carbonic acid, 44; lime, 57; carbonate of lime, $44 + 57 = 101$; magnesia, 41.4; carbonate of magnesia, $44 + 41.4 = 85.4$; silica, 93; alumina, 102.8; protoxide of iron, 72; peroxide of iron, 160.

The following are directions for determining roughly the proportions of those constituents of limestones which are of the greatest practical importance:

1st. Weigh a specimen carefully; calcine it in a crucible, and weigh it again; the loss of weight shows the quantity of *carbonic acid* and *water* together in the specimen, but if it has been well dried previously, at a temperature not sufficient to expel carbonic acid (which requires a bright red heat), the water remaining may be neglected, and the whole loss considered as carbonic acid.

2d. Weigh another specimen of from 30 to 80 grains; reduce it to impalpable powder in a mortar, mix it with three times its weight of caustic potash or soda, and heat it to redness in a silver crucible; dissolve the whole in slightly diluted muriatic acid; the rapidity of solution may be increased by heating the diluted acid to near the boiling point of water. Evaporate the solution, taking care to stir it continually towards the end of the process, until it becomes thick and pasty; this shows that the silica has coagulated. Mix the paste with 8 or 10 times its volume of boiling water; this will dissolve every constituent except the silica; filter the solution, washing the precipitate well with water, taking care to preserve all the water so used along with the original liquor; dry and calcine the precipitate left on the filter; weigh it; this will give the quantity of silica in the specimen.

3d. To the liquor add water of ammonia in excess, to pre cipitate the *alumina*, the *oxide of iron*, and *part of the mag-*

nesia. Then add lime-water by degrees as long as a precipitate falls. That precipitate is the *remainder of the magnesia.* Wash the whole precipitate; dry it; calcine it; weigh it. To the weight thus found, add the weight of the silica found by operation 2, and that of the carbonic acid as calculated from the result of operation 1; subtract the sum from the whole weight of the specimen; the remainder will be the *lime.*

The most important result of the analysis is the proportion of *carbonates* to *silicates* in the stone. The quantity of carbonates may be approximated to in a rough way by multiplying the total quantity of carbonic acid as found by the first process, by the following multipliers, to wit.: if the limestone is not magnesian, 2.3; if there is one equivalent of carbonate of magnesia for each equivalent of carbonate of lime, 2.2; and the truth will almost always be between those limits.

BÉTON.

Béton, or any mixture of cement and sand, or cement, lime and sand, tempered with just sufficient water to convert all the matrix into a thick viscous paste, resists climatic influences and changes, and other usual causes of deterioration in masonry, better than other combination of the same ingredients in which more than this minimum quantity of water is used. This is more emphatically the case when the proportion of water is so great that the mixture becomes plastic, like mason's mortar.

This fact is not only obvious, but is amply confirmed by experience and observation. Only a fixed quantity of water can combine with any given quantity and variety of cement or lime. In béton, or mortar, any excess soon evaporates if exposed to the air, leaving the mass porous, and therefore liable to injury from various agencies, and particularly from

frost. If immersed in sea water, a larger surface is exposed to the action of alkalies and acids known to be more or less injurious in their effects upon light and porous mortar. *The densest mortars that can be produced from given materials are the best,* and the use of a large amount of water is incompatible with the condition of density.

HYDRAULIC CEMENTS AND MORTARS.

The striking and characteristic property of hardening under water, or when excluded from air, may be arranged into five distinct classes, as follows: 1st. The common or fat limes. 2d. The poor or meagre limes. 3d. The hydraulic limes. 4th. The hydraulic cements. 5th. The natural pozzuolanas. The *common fat, or rich limes,* usually contain less than ten per cent. of impurities. In the process of slaking to a paste their volume is augmented to from 2 to $3^1/_2$ times that of the original mass, accompanied by a hissing noise, an elevation of temperature, and the rapid and progressive reduction of the lime to powder. The pastes of fat limes shrink in hardening to such a degree that they cannot be employed as mortar without a large dose of sand. When used alone they are unsuitable for masonry under water, or for foundations in damp soil; but in other situations have an extensive application, possessing as they do great advantages over the other limes on the score of economy, on account of the large augmentation of their volume in slaking. *Paste of fat lime may be added to a cement mortar, in quantities equal to that of the cement, without material diminution of strength.* The *poor, or meagre limes,* in slaking, proceed sluggishly as compared with the rich limes, and seldom produce homogeneous and impalpable powder. They exhibit a more moderate elevation of temperature, evolve less hot vapor, and are accompanied by a much smaller increase of volume than the rich limes. Like the latter they dissolve in water

frequently renewed, though more sparingly, owing to the presence of a large amount of impurities, and like them will not harden if placed in the state of paste under water or in wet soil, or if excluded from contact with the atmosphere, or carbonic acid gas. They should be used for mortar only when it is impossible to procure common or hydraulic lime or cement; in which case it is recommended to reduce them to powder by grinding.

Hydraulic Limes include the three sub-divisions of "limes slightly hydraulic," "hydraulic limes," and limes "eminently hydraulic." If mixed into a stiff paste after being slaked they possess the valuable property of hardening under water, in periods varying from fifteen to twenty days after immersion if "slightly hydraulic;" six to eight days if "hydraulic;" and one to four days if "eminently hydraulic."

As a general fact, these limes undergo in slaking an increase of volume inversely proportional to their hydraulic energy and quickness.

The hydraulic limes in their chemical composition, and for purposes of construction, occupy an intermediate place between the common or fat limes, and hydraulic cements; but they possess no valuable property not present in a preeminent degree in those limestones which furnish hydraulic cement.

It may be said that a mortar has *set*, when it has attained such a degree of induration that its form cannot be altered without causing a fracture, that is, when it has entirely lost its plasticity. As the precise moment when this takes place is somewhat difficult to ascertain in practice, it is important that some more rigorous standard of comparison should be established. The common method is to make use of an iron or steel wire point, loaded to a given weight; and the mortar is assumed to have set when it has become sufficiently stiff and firm to support the point without depression.

Some cements are remarkably quick in exhibiting their hydraulic property, and will lose their plastic state immersed in water at 65° F. in one or two minutes, but afterwards proceed very sluggishly in their induration. These, therefore, setting aside the question of their value in other respects, are admirably adapted to constructions under water, or in positions subjected to immediate submersion. There are others again, which though comparatively slow in developing the first indications of hydraulic energy, yet in a few hours greatly surpass the former in withstanding the wire test, as well as in their ultimate strength and hardness, and are therefore to be preferred in all positions where a very quick induration is not specially important. The former are remarkable for hydraulic *quickness* or *activity;* the latter for hydraulic *energy* or *power*. In order that we may be able to detect and recognize these somewhat obscure properties, it is necessary to have at least two testing wires. Gen. Totten, for his experiments, used a $^1/_{12}$ inch wire, loaded to weigh one quarter of a pound, and a $^1/_{24}$ inch wire loaded to weigh one pound. In the test, make two cakes of the mortar under consideration, by forming them in a circular mould or ring $1^1/_4$ inch in diameter, and $^5/_8$ inch deep. As soon as these cakes are prepared, which is done by pressing the mortar into the ring with a spatula, and smoothing off the upper surface, one of them is immersed immediately in water of an established temperature (65° F.); and the periods of time which it requires to be able to bear respectively the $^1/_{12}$ inch wire weighing one quarter of a pound, and the $^1/_{24}$ inch wire weighing one pound, are accurately noted by the watch. The other cake is left in the air (also brought to 65° F.) until it supports the $^1/_{12}$ inch wire, and is then immersed in water, and the time required to bear the small wire and heavy weight ascertained. The wire test of hydraulic activity, when applied to cement paste *without sand*, does not furnish

even an approximate indication of the relative value of mortars of the same cements when *mixed with a full dose of sand;* for a quick cement might contain one half or three-quarters of its volume of inert matter ground up with it, and consequently be incapable of receiving much sand, and still be superior in hydraulic activity to another, although the latter might be entirely unadulterated and its capacity for sand unimpaired.

In pronouncing on the value of cements from a comparison of their relative hydraulic activity, they should therefore be mixed with two and a half to three times their volume of sand. Even with this precaution the result is far less reliable than some simple device for trying the strength of the mortars when ten or twelve days old. As an evidence of the truth of this remark it may be stated, that although eminent hydraulic activity or quickness is not necessarily accompanied by inferior hardness and strength, and conversely neither is a slow-setting cement necessarily a strong one; still, within the range of experiments of the author, it is somewhat remarkable that the *quickest cements* gave the *worst results*, and the *slowest ones the best.*

METHOD OF ASCERTAINING HYDRAULIC VALUE OF STONE.

Changes in the character of a cement stone often take place slowly and progressively within the limits of individual beds, in directions both perpendicular and parallel to the planes of stratification, without any perceptible variation in the appearance of the stone or in its homogeneousness; and simply require for their correction a modification in either the *proportion* of the different layers introduced into the combination, in the *degree* of calcination to which they are subjected, or in *both.*

It is therefore important that some practical method of ascertaining the absolute as well as the relative value of these several kinds of stone should be pointed out; and it is equally important that such a method should be simple, inexpensive, and easy of application.

The only apparatus required for this purpose is a crucible of the capacity of one pint or thereabouts, and a mortar and pestle.

The crucible should be perforated near the bottom, in several places, to give an upward current of air and facilitate the escape of carbonic acid gas, and should be provided with a cover likewise perforated. When access can be had to a grate fire of anthracite coals this single crucible may be advantageously replaced by several of smaller size. When more than one is used, however, care must be taken to so regulate the fire that all will be subjected to an equal degree of heat throughout the burning. The stone to be tried, after being broken into pieces as nearly equal in size as possible, and not exceeding three quarter inch cube, is introduced into the crucibles, supposing several to be employed, each receiving the same number of fragments, if practicable. All the crucibles, with the covers on, are then imbedded in the fire and covered up with coals, so that the top and bottom portions will attain a bright red heat simultaneously. This last precaution is essential to the complete success of the process. In about forty-five minutes after the stone has reached a bright red heat, one of the crucibles is removed from the fire; the others following in succession at intervals of forty-five minutes. In order to secure similar results with a single large crucible, two or three of the fragments are taken out at the end of the first forty-five minutes of bright red heat, and others subsequently, as the periods of time above designated are reached, allowing not less than four and a half hours to the last portions, or perhaps six

hours, should the stone be very refractory, which will be sufficient to expel all the carbonic acid gas, and to carry some varieties of cement stone, if broken up as directed, to the point of incipient vitrification. A long continued bright red heat operates in a singular manner upon some argillaceous varieties of cement, bordering on the intermediate lines, in conferring upon them remarkable hydraulic properties and energy which they do not possess at the point of complete calcination, but which may have been present in a lower degree before all the carbonic acid was expelled. In order to render certain the detection of stone possessing this property, when its presence is suspected, it is recommended to continue the calcination of some of the fragments for eight or nine hours. By means of the several aforementioned crucibles, we obtain portions of the stone that are overburnt, other portions that are insufficiently burnt, and an intermediate class, among the several members of which will be discovered good cement, if the stone be capable of yielding it. There will also be indicated, to an extent sufficiently exact for practical deductions, the relative degrees of calcination adapted to the several varieties operated upon, with their exact and appropriate maximum limits, respectively. These specimens, unless the stone belongs to some grade of common, meagre, or hydraulic limes, will not slake when sprinkled with water.

Upon being separately reduced to powder in a mortar, mixed to a stiff paste with fresh water, and immersed in water, either fresh or salt, they will indicate in their respective times of setting their relative hydraulic energy, and approximately their value as cements.

Whether the stone be suitable for cement or otherwise it will be found, with very few if any exceptions, that the unburnt fragments, those which contain in the centre a small core of partially raw stone, as indicated by its density, color

and hardness, and which effervesce briskly with dilute hydrochloric acid, will be superior in hydraulic activity to the more highly calcined samples; and will set under water at 65° F. in periods varying from five to fifty minutes.

Those which do not effervesce with dilute acid, and have consequently parted with all their carbonic acid gas, will exhibit a less degree of hydraulic quickness, and will require a longer time by 25 to 50 per cent. to harden under water; while the overburnt samples, those in which the calcination has proceeded to the verge of vitrification, will in some instances be almost entirely wanting in hydraulic activity, and in others will have this property very much impaired. It by no means follows that this last mentioned class is inferior to the others in the ultimate energy and strength of its gangs or mortars.

By carefully subjecting from time to time the several undivided layers of a quarry to the trials above indicated, taking care to secure a faithful fulfillment of all the conditions specified, so that each will receive precisely the same treatment, we are able to ascertain with sufficient accuracy, and to keep constantly in view the peculiar character of each kind of stone; such as its appearance when properly calcined, the requisite degree and duration of heat, the correct limits of calcination, and consequently the best mode of burning it on a large scale (whether by itself or mixed with the other layers), and the most advantageous proportions in which it should enter into a combination of the whole.

Experience teaches us that the physical appearance of calcareous stones (limestone and marbles of various kinds) furnishes no indication of their qualities after calcination. Even a chemical analysis of the raw stone is to a certain extent unreliable, and deductions from it, under the most favorable circumstances, can only be regarded as tolerable approximations, and are not unfrequently contradictory.

The hydraulic induration is due in a great measure to the chemical combination of lime and silica, a union which is partially perfected in the dry way during the burning, and is subsequently carried on and completed by the agency of water.

The practical strength of Mortars and Concrete, considered with regard to their tenacity, hardness, and power of resisting compression, depends upon four essentially distinct conditions:

1st. The constant resistance of the parts enveloped by the matrix, whether composed of sand, gravel, pebbles, fragments of brick or stone, or a mixture of them all.

2d. The resistance, varying and generally increasing with time, of the matrix or cementing matter.

3d. The force of adhesion between the matrix and the other parts, resulting in part from the former penetrating the interstices of the latter, and in part from the chemical affinities existing between them.

4th. The strength due to the interlacement of the enveloped parts with each other, which produces leverage and friction among them and enlarges the surface of least resistance.

It might be inferred, theoretically, that the capacity of mortars and concretes, possessing no voids, to resist any particular kind of strain, cannot surpass that of its matrix or gang; or, rather, cannot be equal to it except when the inherent strength of the enveloped parts, as well as the adhesion between them and the matrix, equals or exceeds the resisting power of the latter.

In practice, when these conditions do approximately obtain in exceptional cases, mortars are weakened by the addition of sand or any of the substances above mentioned. These latter have the important effect, however, of preventing or diminishing shrinkage, of hastening the indura-

tion of rich limes, and of rendering all kinds of mortars less liable to crack in drying, which is often of very great advantage.

It might also be inferred that the minimum amount of the cementing material that can be used in any case is exactly equal to the volume of the voids in the sand when the latter is well compacted. This theory supposes that there is no shrinkage in the matrix while hardening, and that the manipulation is complete. But as these conditions can never be fully attained in practice, it is unsafe to descend to this inferior limit. Moreover, mortars composed on this principle would be deficient in both adhesive and cohesive power, from the fact that the particles of sand would present a large area, practically void of matrix, to the surfaces of the solid materials that are to be bound together, and would for the same reason be in more or less intimate contact with each other throughout the mass. In order to avoid these defects it is customary to determine the amount of cementing matter, to be used in any particular case, by adding 45 to 50 per cent. to the volume of void space in the sand. One method of ascertaining these voids is to determine the volume of water which a well-known volume of the sand (damp and well compacted in a vessel) will receive.

METHODS OF SLAKING LIME.

Three methods of slaking lime are usually described in works on mortars; on the continent of Europe the third method, and in the United States the second and third are seldom resorted to in practice. The first, or ordinary method, termed *drowning*, from the excessive quantity of water sometimes injudiciously employed, consists in pouring upon the lumps of lime collected together in a layer of uniform depth, not exceeding six to eight inches, either in a water-tight wooden box or a basin formed of the sand to be

subsequently added in making mortar, and coated over on the inside with lime-paste to render it impervious to water, a sufficient measure of fresh water (previously ascertained approximately by trial,) to reduce the whole to the consistency of thick pulp. It is important that all the water required for this purpose, which, with the different limes, will vary from two and a half to three times the volume of the quicklime, should be added at the outset, or at least before the temperature becomes sensibly elevated. In this condition the lime will remain entirely submerged and comparatively quiescent until after an interval of five to ten minutes the water becomes gradually heated to the boiling point, when a sudden evolution of vapor, a rapid increase in volume, and a reduction of the lime to pulp ensues. This process is liable to great abuse at the hands of workmen, who are apt to use either too much water, thus conferring upon the slaked lime a condition of semi-fluidity and thereby injuring its binding qualities, or not having used enough in the first instance, they seek to remedy the error by adding more after the extinction has well progressed and a portion of the lime is already reduced to powder; thus suddenly depressing the temperature and chilling the lime, which renders it granular and lumpy.

As soon as all the water required has been poured upon the lime it is recommended to cover up the vessel containing it with canvas, or boards, in order to concentrate the heat and the escaping vapor, and direct their action upon the uppermost portions deprived of immediate contact with the water by the swelling of the portions at the bottom. When it is not practicable to apply the covering, a tolerable substitute is found in the sand to be subsequently added to the mortar. This can be spread over the lime in a layer of uniform thickness after the slaking has well progressed.

Another precaution of equal and perhaps greater import-

ance, is, not to stir the lime whilst slaking; but to allow it gradually to absorb the water by capillary attraction and its natural avidity for it, taking care that all portions are supplied with it to that degree requisite to produce a paste of the slaked lime, and not a powder.

When the lime is to be used for whitewashing, or grouting, the water should be added at the outset in larger quantities than specified above, and the whole mass should be run off while hot into tight casks, and covered up to prevent the escape of water.

In slaking, the essential point is to secure, if possible, the reduction of all the lumps. It will be found difficult to obtain this result with the hydraulic varieties, and the difficulty increases in a direct ratio with the hydraulic energy, until we reach the intermediate limes or the inferior limit of cement, when the reduction must be effected by mechanical means. Even with these hydraulic limes that do slake, it is often necessary to employ a mortar mill to reduce the lumps, a condition which should always be secured, as these lumps constitute not only a dangerous substitute for sand if left intact, but furnish when pulverized, the most energetic portions of the gang. The *second* method of slaking (by immersion) is seldom used owing to the difficulties and expense attending it. A modification of it consists in sprinkling the broken fragments formed into heaps of suitable size, with one fourth or one third of their volume of water. This should be applied from the rose of a finely gauged watering-pot, after which the lime should be immediately covered with the sand to be used in the mortar. In this condition it should not be disturbed for at least a day or two, and the opinion prevails in the southern portions of Europe that the quality of the lime is improved by allowing the heaps to remain several months without any other protection from the weather than an ordinary shed open on the sides.

SPONTANEOUS SLAKING.

Quicklime has a great avidity for water, and when not secured from direct contact with the atmosphere, gradually absorbs moisture from it and falls into powder, exhibiting but very slightly the other phenomena usually developed in slaking. Hydraulic limes are greatly injured by spontaneously slaking. The first process (drowning) is the most advantageous in nearly every case, *provided the precaution is taken to pour on at the outset all the water required to produce a stiff paste, but no more.*

PRESERVATION OF LIME.

The paste of fat lime, whatever may have been the mode of extinction, may be preserved intact for an indefinite length of time if kept from contact with the air. It is usual to put it in tight casks, or in trenches covered up with sand, or when shed-room is available to form it into rounded heaps, similarly protected, and under cover.

MAKING MORTAR.

Extensive operations, requiring large quantities of mortar, are frequently carried on without the aid of a mortar mill of any kind. When ordinary lime mortars are thus made by hand, it is customary and convenient to slake the lime by the first method described, and in no greater quantity than may be required for immediate use. The operation should be conducted under a shed.

The measure of sand required for the "batch" is first placed upon the floor and formed into a basin for the reception of the unslaked lime; after this, the latter is put in, and the larger lumps broken up with a mallet; the quantity of water necessary to form a stiff paste is let on; the lime is then stirred with a hoe as long as there is any evolution of

vapor, after which the ingredients are well mixed together with the shovel and hoe, a little water being added occasionally if the mass be too stiff. At this stage of the operation it is customary to heap the mortar compactly together and allow it to remain until required for use. When circumstances admit, it should not be disturbed for several days, and during the period of its consumption should be broken down and "tempered" in no larger quantities than may be required for use from day to day.

It is believed that certain slight modifications of this common method of procedure can be made with decided advantage in the final results:

1st. All the lime necessary for any required quantity of mortar should be slaked at least one day before it is incorporated with the sand.

2d. The sand-basin to receive the unslaked lime should be coated over on the inside with lime-paste, to prevent the escape of water.

3d. All the water required to slake the lime to a stiff paste should be poured on at once; this will completely submerge the quicklime. The heap should then be covered over with tarpaulin or old canvas and left until next day.

4th. The ingredients should be thoroughly mixed and the mortar heaped up for future use.

The mortar used by Col. Barnard in the construction of Forts Richmond, and Tompkins, New York harbor, was made by hand. When required for stone masonry, or concrete, it was composed of hydraulic cement and sand, without lime. Four men constituted a gang for measuring out and mixing the ingredients, who proceeded to the several steps of the process in the following order:

1st. The sand is spread in a rectangular layer of two inches in thickness.

2d. The dry cement is spread equally all over the sand.

3d. The men place themselves, shovel in hand, two on each side of the rectangle, at the angles, facing inwards. Furrows of the width of a shovel are then turned outwards, along the ends of the rectangle, until the whole bed is turned. The two men on one side thus find themselves together, and opposite the two on the other side, having, of course, left a vacant space transversely through the middle of double the width of a shovel. They then move back to their original positions in turning furrows as before, when the bed occupies the same space that it did previously to the first turning. The turning is executed by successively thrusting the shovel under the material and turning it over about one angle as a pivot. Each shovel thus moves to the middle of the bed, where it is met by the one opposite, when each man moves back to the side in dragging the edge of his shovel over the furrow he has just turned.

4th. A basin is formed by drawing all the material to the outer edge of the bed.

5th. The water is poured into the basin thus formed.

6th. The material is thrown back upon the water, absorbing it, when the bed occupies the same space that it did at the beginning.

7th. The bed is turned twice by the process above described. If required for mason's use, the mortar is then heaped up to be carried where it is required. If for concrete, (the mortar occupying the rectangular space as at first,) then

8th. The broken stones are spread equally over the bed.

9th. A bucket of water, more or less, (depending upon the quantity of stones, their absorbing power, and the temperature of the air,) is sprinkled over the bed.

10th. The bed is turned once as before and then heaped up for use. The act of heaping up, which is done with care, has the effect of a second turning. When the mortar is required

in very small quantities, to avoid deterioration, instead of proceeding to the 4th step of the manipulation, the mixture of cement and sand is heaped up and the water added and paste formed with the hoe in such quantities as required.

The mortar at Forts Richmond, and Tompkins, whether required for stone masonry or for concrete, contained 308 lbs. of hydraulic cement powder which produced 3.7 cub. ft. of stiff paste; and 12 cub. ft. of loose sand, equal to about 9.75 cub. ft. well compacted. These ingredients, being incorporated, produced 11.75 cub. ft. of rather thin mortar.

COMPOSITION OF MORTAR USED AT FORT WARREN.

The mill-made mortar for the *stone* masonry at Fort Warren was composed of lime, hydraulic cement and sand, in the following proportions, viz.: 325 lbs. of dry cement, producing 3.8 cub. ft. of stiff paste; 120 lbs. Rockland lime, producing 4 cub. ft. of stiff paste; $19^1/_4$ cub. ft. of loose sand, equal to $14^1/_2$ cub. ft. well compacted. These ingredients being well mixed, make $18^1/_2$ cub. ft. of good mortar. For mortar for *brick* masonry, the same quantities of lime and cement received but $15^3/_4$ cub. ft. of loose sand, equal to 12 cub. ft. well compacted; giving 16 cub. ft. of good mortar.

Some engineers object to the use, in work of importance, of mortars containing so large a proportion of sand as that adopted at Forts Richmond, and Warren; others again, very seldom add lime to their cement mortars. Touching this last mentioned point, recent experiments show, with a uniformity quite satisfactory, that most American cements will sustain, without any great loss of strength, a dose of lime paste equal to that of the cement paste; while a dose equal to one half to three fourths the volume of cement paste may

safely be added to any energetic Rosedale cement without producing deterioration in the quality of the mortar to a degree requiring any serious consideration. Neither is the hydraulic activity of the mortar so far impaired by this limited addition of lime paste as to render them unsuitable for concrete under water or other submarine masonry; while for constructions not subject to immediate submersion, or the action of the returning tide, it is to be preferred on many accounts.

By the use of lime we secure the double advantages of a rather slow mortar, one that is in no danger of setting before it reaches the mason's hands, and a cheap mortar. We also avoid the principal serious objection to the use of a quick-setting mortar due to tardy attendance on the masons, and consequently the constant breaking up of the incipient set on the mortar-board, whereby cements are degraded in energy to a level with ordinary hydraulic limes.

POINTING MORTAR.

In laying up masonry of any character, whether with common or hydraulic mortar, the exposed edges of the joints will naturally be deficient in density and hardness, and therefore unable to withstand the destructive action of the elements; particularly variations in temperature producing extreme heat and cold. It is therefore customary to fill the joints as compactly as possible to the depth of about half an inch with mortar prepared especially for the purpose. This operation is called "pointing," and the mortar "pointing mortar." The cleaning out of the joints to the requisite depth should take place while the mortar is new and soft; and (in stone masonry) when the stones come in contact, or nearly so, the joints must be enlarged to the width of about three sixteenths of an inch by a stone-cutter. Pointing-mortar is compounded of a paste of finely ground cement and clear

sharp silicious sand, in such proportions that the volume of cement paste shall be very slightly in excess of the volume of voids in the sand. These voids should be carefully ascertained.

The measure of sand will generally vary between two and a half and two and three fourths that of the cement paste; or, by weight, one of cement powder to from three to three and one third of sand. The mortar when ready for use should appear rather incoherent and quite deficient in plasticity.

The mixing should take place under shelter, in an iron or stone mortar, or some other suitable vessel, and in quantities of not over two or three pints at a time. Before pointing, the wall should be thoroughly saturated with water and kept in such a condition that it will neither absorb water from the mortar nor impart any to it; two conditions of special importance, the first being paramount. Walls should not be allowed to dry too rapidly after pointing, but should be kept moist for several days, or, better still, for two or three weeks. Pointing in hot weather should therefore be avoided if possible.

CONCRETE.

Natural hydraulic cement, to which, under circumstances requiring only a moderate degree of energy and strength paste of fat lime is sometimes added in quantities seldom greatly exceeding that of the cement, is almost invariably used as the basis of the concrete mortar; and the concrete when made is at once deposited in its allotted place, and well rammed in horizontal layers of about six inches in thickness, until all the coarser fragments are driven below the general surface.

The ramming should take place before the cement begins to set, and care should be taken to avoid the use of too much

water in the manipulation. The mass when ready for use should appear quite incoherent, containing water, however, in such quantities that a thorough and hard ramming will produce a thin film of free water upon the surface under the rammer, without causing in the mass a gelatinous or quick-sand motion.

It will be found in practice that cements vary very considerably in their capacity for water and that fresh ground cements require more than those that have become stale. An excess of water is, however, better than a deficiency, particularly when a very energetic cement is used, as the capacity of this substance for solidifying water is great. A too rapid desiccation of the concrete might involve a loss of cohesive and adhesive strength if insufficient water be used. Concrete is admirably adapted to a variety of most important purposes, and is daily growing into more extensive use and application. For foundations in damp and yielding soils and for subterranean and submarine masonry, under almost every combination of circumstances likely to occur in practice, it is superior to brick-work in strength, durability, and economy; and in some exceptional cases is considered a reliable substitute for the best stone, while it is almost always preferable to the poorer varieties.

For submarine masonry, concrete possesses the advantage that it may be laid without exhausting the water, (which, under the most favorable circumstances is an expensive operation,) and also without the aid of a diving bell or submarine armor. On account of its continuity and impermeability to water, it is well suited to the purposes of a substratum in soils infected with springs; for sewers and conduits; for basement and sustaining walls; for columns, piers and abutments; for the hearting and backing of walls faced with bricks, rubble and ashlar-work; for pavements in areas, basements and cellars; for the walls and floors of cisterns,

vaults, etc. Fence or railing posts of the minimum size consistent with the requisite degree of strength, may be firmly set and retained permanently in their upright position by surrounding them with concrete, or rather by inserting them in a concrete foundation. The mortar for this purpose need not be very rich in cement, and in quantity might barely exceed the volume of voids in the coarse materials. One foundation properly prepared would serve for an indefinite period of time, and the posts could be renewed as often as decay rendered it necessary.

It is believed that by slightly tapering the lower end of the posts, so as to render their removal simple and easy, and by lowering the entire foundation so as to place its upper surface below the reach of the plough, an excellent and inexpensive system of movable fences for farmers' use could be devised.

It is considered injurious to ram concrete deposited under water. To obtain the necessary density we must depend on the rake or some similar instrument gently used to keep the layers approximately level, and on the weight of the superincumbent mass.

Some eminent French engineers recommend the foundation in a single mass or layer of concrete work under water, whether for foundations, platforms, or areas. The only advantage to be derived from this method over the one of thin continuous layers, formed successively over extensive areas, appears to be the increased density of the portion first laid. This, before it begins to set, becomes well compressed by the weight subsequently added. In founding with concrete, it is usual to surround the place to be occupied by the work with sheet-piling driven somewhat below the level of the base of the structure, and then to remove the soil to the requisite depth. In certain cases, when the soil is very firm and the foundation has to reach to a small depth only, the

piling need not be used ; in others, where these conditions do not obtain, it may be necessary to use piles of extra strength and length and to support them against the pressure of the earth by braces at top. In order to prevent currents that might wash the concrete, holes should be left in the piling, near the top, so that the water will remain at the same level within and without.

In founding over springs, the action of which might drench the concrete and wash out the cement, they might be stopped off by tarred canvas stretched over the area.

Concrete walls are frequently revetted or faced with stone. In fact, this is a common method at the present day of constructing sea-walls and sustaining walls. The stone facing is generally in courses composed of headers and stretchers alternately. The stretchers are so jointed on the end as to be a few inches longer on the back than on the front. The vertical joints on the headers, being formed at a corresponding angle with the face, while the tails of the headers reaching entirely through the concrete backing are left undressed, the wall becomes a firm and connected system of dovetailing. In constructing a wall of this kind, as soon as a course of facing stone is laid, the back, to its entire thickness, is levelled up with concrete, rammed in compact layers not exceeding one foot in depth, the surfaces of the stone having previously been freed from dust, moistened with water and coated over with mortar, in order to insure the adhesion of the concrete.

When concreting is carried on in connection with stone cutting and stone masonry operations in general, the spalls, chips, and irregular fragments made by the cutters can be converted into excellent concrete material at a moderate cost.

Some blocks of concrete were made in the harbor of New York in 1860, in the course of experiments, by injecting a

thin paste of light colored Rosedale cement without sand, into boxes filled with coarse gravel and pebbles, and submerged in sea water. The cement was mixed in some cases with fresh, in others with sea water, in the proportion by volume, of 48 of water to 100 of cement powder. It was poured through a tin pipe one and a half inches in diameter and 18 feet in vertical height. The boxes were $5^9/_{10}'' \times 5^9/_{10}'' \times 36'$ clear dimensions, and were perforated with small holes to facilitate the ejection of the water. At the expiration of some weeks the boxes were taken from the water and the blocks removed. The cement was found to have penetrated to the remotest corners of the boxes and to have filled perfectly the interstices in the gravel and pebbles. The cement mixed with sea water furnished by no means a stable concrete. A few days after exposure to the air it began to crack all over the surface, and was very deficient in cohesive strength and solidity. That mixed with fresh water retained its sharp corners and angles perfectly; no cracks or other evidences of decomposition appeared. The blocks remained solid and compact, and when broken for examination it appeared that the adhesion to the pebbles was very good and that every void was perfectly filled.

There is reason to believe that the cream of cement would be improved by the addition of eight to ten per cent. of fat lime paste, and that the long pipe can be advantageously replaced by a syringe or force pump of suitable form; for it is evident that the pressure due to the vertical height of the pipe, supposing a perfect fluid to be used, is only partially secured by the semi-fluid cement, and can only be augmented by thinning the paste or by lengthening the pipe. Any arrangement by means of which a stiff paste can be injected would be an improvement.

An ingenious device for laying stone masonry in cement-mortar, under water, was practiced by Major Alexander, in

the construction of the Minot's Ledge light house, Boston Harbor. It consists in protecting the mortar from the disolving action of the water during the descent of the stone to its bed, by an envelope of muslin sufficiently loose in texture to allow the mortar to ooze through between the fibres, and thus form a bond with stone previously laid. The idea is analogous to that followed by some Italian engineers in repairing and protecting submarine masonry, by concrete rammed into position in bags of loose, open texture. It may be applied in the following manner, viz.: A piece of muslin of suitable quality, and somewhat larger than the bed of the stone to be laid, is first spread out on a horizontal surface and covered with a coat of mortar of the thickness desired in the work, and of an area somewhat exceeding that of the bed of the stone. On this mortar the stone is then carefully placed and allowed to remain there until the mortar begins to stiffen a little, the margin of the cloth exterior to the stone having been folded up against the sides of the latter and secured there by cords leading over the top. The stone is then lowered to its position on the wall, rammed into place, and not again disturbed. This plan, if applied with care, may be made to subserve a good purpose. Cement paste *without sand* was used in all cases.

APPEARANCE OF GOOD TIMBER.

In the same species of timber, that specimen will in general be the strongest and the most durable which has grown the slowest, as shown by the narrowness of the annular rings. The cellular tissues, as seen in the medullary rays, should be hard and compact. The fibrous tissues should adhere firmly together and should show no wooliness at a freshly cut surface, nor should it clog the teeth of the saw with loose fibres. If the wood is colored, darkness of color is in general a sign of strength and durability. The freshly

cut surface of the wood should be firm and shining, and should have somewhat of a translucent appearance. A dull, chalky appearance is a sign of bad timber. Amongst resinous woods, those which have the least resin in their pores; and among non-resinous woods, those which have least sap or gum in them, are in general the strongest and most lasting.

ENGINEERING GEODESY.

Finding the Meridian.—For the purpose of laying down the direction of the true north, on the plan of an engineering survey, the angle which one of the principal station-lines makes with the meridian must be determined, though not with the same accuracy that is required for astronomical and geographical purposes. The following are some of the methods:

By the two greatest elongations of a circumpolar star.—This, the most accurate method, consists in observing the greatest and least horizontal angles made by a star near the pole with a station-line of the survey when the star is at its greatest distances east and west of the pole, and taking the mean of those angles, which is the true azimuth of the station-line or horizontal angle which it makes with the meridian. In the northern hemisphere the pole-star *a*, Ursa Minoris, is the best for this purpose. This method, however, is seldom practicable with an ordinary theodolite as, in general, one of the observations must be made by daylight.

By equal altitudes of a star.—The theodolite being at a station in the station-line chosen, measure the horizontal angle from the station-line to any star which is not near the highest or lowest point of its apparent daily course, and take also the altitude of that star. Leave the vertical circle clamped and let the instrument remain perfectly undisturbed

until the star is approaching the same altitude at the other side of its apparent circular course. Then, without moving the vertical circle, direct the telescope towards the star, clamp the vernier plate, and by the aid of its tangent-screw follow the star in azimuth with the cross wires until it arrives exactly at its former altitude, as is shown by its image coinciding with the cross wires ; then measure the horizontal angle between the new direction of the star and the station-line ; the mean between the two horizontal angles will be the true azimuth of the station-line.*

In both the preceding processes it is to be understood that the *mean of two horizontal angles* means their *half sum* when they are at the same side of the station-line, but their *half difference* when they are at opposite sides. The second method may be applied to the sun, observing the sun's west limb in the forenoon and east limb in the afternoon, or *vice versa* ; but in that case a correction is required owing to the sun's change of declination. †

When the sun's declination is changing toward the $\left\{ \begin{matrix} \text{north} \\ \text{south} \end{matrix} \right\}$, the approximate direction of the meridian as found by the method just described, is too far to the $\left\{ \begin{matrix} \text{right} \\ \text{left.} \end{matrix} \right\}$ The correction required is given by the formula, $\dfrac{\text{change of sun's declination}}{2} \times$ sec. latitude $\times$ cosec. one half angular motion of sun between the observations (1).

---

* In observing at night with the theodolite, it is necessary to throw, by means of a lamp and a small mirror, enough of light into the tube to make the cross wires visible.

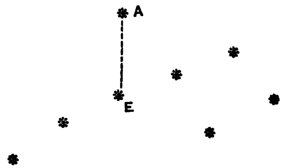
† At the equinoxes, the rate of change of the sun's declination is about 59 seconds per hour, and it varies nearly as the cosine of the sun's right ascension.

BY ONE GREATEST ELONGATION OF A CIRCUM-POLAR STAR.

To use this method, the declination of the star and the latitude of the place should be known; then *sine* of azimuth of star at greatest elongation = *cos* of declination ÷ *cos.* latitude (2), and this azimuth being added to or subtracted from the horizontal angle between the station-line and the star when at its greatest elongation (according as the station-line lies to the same side of the meridian with the star, or to the opposite side), gives the azimuth of the station-line.

APPROXIMATE METHOD BY OBSERVING CERTAIN STARS.

It is remarked that a great circle traverses the pole-star (Ursa Minor), and the star Alioth in the Great Bear (ε Ursa Major) passes very near the pole. Hence, in the northern hemisphere a meridian-line may be fixed approximately by observing with the aid of a plumb-line the instant when those two stars appear in the same vertical plane, as here shown.



The pole-star is marked A.

When two points on the earth's surface have the same latitude but different longitudes the horizontal angle made by their meridians with each other, is found by the following equation: *sin.* $^1/_2$ horizontal angle = *sin.* $^1/_2$ diff. of long. $\times$ *sin.* lat. (3).

TAKING ALTITUDES BY THE SEXTANT.

When the altitude of an object is taken at sea, by measuring with a sextant its angular elevation above the visible

sea-horizon, a correction must be made by subtracting the *dip* of that horizon, that is, its apparent angular depression below a truly horizontal line traversing the eye of the observer. The amount of that depression is uncertain, owing to the variable refractive power of the atmosphere, but on an average it is given approximately by the following formula, in which h denotes the height of the observer's eye above the sea, and r the radius of curvature of the surface of the sea:

$$\text{Dip in seconds} = {}^{9}/_{10} \times 206264''.8 \frac{\sqrt{2h}}{r} = 57''.4 \sqrt{h \text{ in feet.}}$$

TO FIND THE LATITUDE OF A PLACE.

METHOD 1.—*By the Mean Altitude of a Circumpolar Star.*

Take the altitudes of a circumpolar star at its upper and lower culmination (which positions are known by watching for the instants when the altitude is greatest and least). From each of those *apparent* altitudes subtract the correction for refraction; the mean of the *true* altitudes thus found is the latitude of the place.

METHOD 2.—*By One Meridian Altitude of a Star.*

Observe the meridian altitude of a star by watching for the instant when its altitude is greatest or least, and subtract the correction for refraction, and also for dip if necessary. The complement of the true altitude is the *zenith distance.* Find the declination of the star from the Nautical Almanac (which is published four years in advance): then, if the star is between the zenith and the equator, Lat. = zenith distance + declination (1).

If the star is between the equator and the horizon, Lat. = zenith distance — declination (2).

If the star is between the zenith and the elevated pole, Lat. $=$ declination $-$ zenith distance (3).

If the star is between the elevated pole and the horizon, Lat. $= 180^\circ -$ declination $-$ zenith distance (4).

ASTRONOMICAL REFRACTION.

The refracting action of the atmosphere causes the altitudes of the stars to appear greater than they really are. The correction for refraction, therefore, is always to be subtracted from an altitude. Its value may be found in seconds, approximately, by the following formula: Refraction $= 58'' \times$ *cotang.* apparent altitude.

REDUCTION OF ANGLES TO THE CENTRE OF THE STATION.

It sometimes happens that the theodolite cannot be planted exactly at a station in a trigonometrical survey, but has to be placed at a short distance to one side of it. In such cases the angle actually measured between two objects, is reduced to the angle which would have been measured had the theodolite been exactly at the station, by a correction which is calculated approximately as follows:

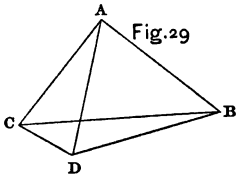


Fig.29

In Fig. 29, let C be the station, D the position of the theodolite, A and B two objects, ADB the horizontal angle between them as measured at D, ACB the required horizontal angle at the station C. Measure CD and the angle

ADC. Calculate *AC* and *CB* approximately, as if *ACB* were equal to *ADB*; then $ACB = ADB - 206264''.8 \left\{ \frac{sin.\ ADC}{AC} - \frac{sin.\ BDC}{BC} \right\}$. The above formula gives the correction in seconds when *D* lies to the *right* of both *CA* and *CB*. When it lies to the left of *CB sin. BDC* changes its sign. When to the left of *CA sin. ADC* changes its sign.

LEVELLING BY THE BAROMETER AND THERMOMETER

May occasionally be used for engineering purposes to take flying levels in exploring the country. The following formula is sufficiently correct for that object. Let the quantities observed be denoted as follows:

	At the lower Station.	At the higher Station.
Height of the mercurial column in the barometer..................	*H*...........	*h*
Temperature of the mercury in degrees of Fahr., as shown by the "attached" thermometer........	*T*...........	*t*
Temperature of the air, in degrees of Fahr., as shown by the "detached" thermometer.............................	*T'*...........	*t'*

Then the height of the higher station above the lower in feet $= 60360 \{ \log.\ H - \log.\ h - .000044\ (T - t \}$. For rapid calculation, the following, though less exact, is convenient, viz.: Height in feet $= 56300\ (\log.\ H - \log.\ h) \left(1 + \frac{T + t}{900}\right)$. In the absence of logarithms, the following formula may be used for heights not exceeding about 3000 feet. Correct the barometric reading at the higher station as follows: $h' = h \left(1 + \frac{T - t}{10000}\right.$, then height in

feet $= 52428 \frac{H - h'}{H + h'} \left(1 + \frac{T' + t' - 64}{986}\right)$ nearly. The preceding formulæ are applicable to the mercurial barometer. They are also applicable to the "aneroid" barometer, with the exception of the correction depending on the temperature by the attached thermometer. The aneroid barometer, if very skillfully constructed, may be made to require no appreciable correction for the effect of its own temperature on its indications. Should it need such correction, the amount can only be determined by an experimental comparison between the individual aneroid barometer and a mercurial barometer.

Another method of taking flying levels, depending like the barometric method upon the pressure of the air, is that of determining the boiling point of pure water by a very sensitive thermometer.

That boiling point falls very nearly at the rate of one degree of Fahr. for every 543 feet of ascent; and still more nearly according to the following formula: z in feet $= 517 (212° - T) + (212° - T)^2$ (4), T being the boiling point on Fahr. scale, and z the height of the station where the experiment is made above a station where the boiling point is 212°. To compare the levels of two stations, the boiling point of pure water is to be observed at each, and the quantity z is to be calculated by formula (4) for each of the boiling-points; when the difference between those quantities z, corrected for the temperature of the air, will be the approximate difference of level.

PARABOLIC FIGURES OF THE THIRD DEGREE.

The parabolic figures to which the following rules apply, are of the following kind (see Figs. 30 and 31). One boundary is a straight line AX, called the *base*, or *axis*; two other boundaries are either points in that line, or straight lines at

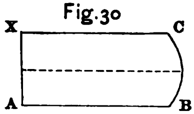


Fig. 30

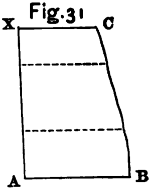


Fig. 31

right angles to it, such as AB and XC, called *ordinates;* and the fourth boundary is a curve BC of the parabolic class and of the *third degree*, that is, a curve whose *ordinate* (or perpendicular distance from the base AX) at any point is expressed by what is called an algebraical function of the third degree of the abscissa (or distance of that ordinate from a fixed point in the base).

An algebraical function of the third degree of a quantity consists of terms not exceeding four in number, of which one may be constant, and the rest must be proportional to powers of that quantity not higher than the cube.

Rule A.

Divide the base, as in fig. 30, into two equal parts or intervals; measure the endmost ordinates AB and XC, and the middle ordinate (which is dotted in the figure) at the points of division; add together the endmost ordinates, and four times the middle ordinate, and divide the sum by six; the quotient will be the *mean breadth* of the figure, which being multiplied by the length of the base AX, will give the area.

Rule B.

Divide the base, as in fig. 31, into three equal intervals; measure the endmost ordinates AB and XC, and the two intermediate ordinates (which are dotted) at the points of division; add together the endmost ordinates and three

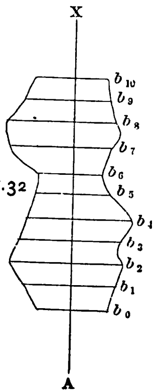
times each of the intermediate ordinates; divide the sum by eight; the quotient will be the mean breadth of the figure, which being multiplied by the length of the base AX, will give the area.

In applying either of those rules to figures whose curved boundaries meet the base at one or both ends, the ordinate at each such point of meeting is to be made $= 0$.

ANY PLANE AREA.

Draw an axis or base line AX, in a convenient position. The most convenient position is usually parallel to the greatest length of the figure or area to be measured. Divide the length of the figure into a convenient number of equal intervals, and measure breadths in a direction perpendicular to the axis at the two ends of that length and at the points of division, which breadths will of course be one more in number than the intervals. (For example, in fig. 32 the length of

Fig. 32



the figure is divided into ten equal intervals, and eleven breadths are measured at b_0 b_1, etc.) Then the following rules are exact, if the sides of the figure are bounded by

straight lines and by parabolic curves not exceeding the third degree, and are approximate for boundaries of any other figures.

Rule A.

("Simpson's First Rule," to be used when the number of intervals is even.) Add together the two endmost breadths, *twice* every second intermediate breadth, and *four times* each of the remaining intermediate breadths; multiply the sum by the common interval between the breadths, and divide by 3; the result will be the area required. For two intervals, the multipliers for the breadths are 1, 4, 1 (as in Rule A of the preceding article); for four intervals, 1, 4, 2, 4, 1; for six intervals, 1, 4, 2, 4, 2, 4, 1; and so on. These are called "Simpson's Multipliers." *Example:* Length, 120 feet, divided into six intervals of 20 feet each.

Breadths in feet and Decimals.	Simpson's Multipliers.	Products.
17.28	1	17.28
16.40	4	65.60
14.08	2	28.16
10.80	4	43.20
7.04	2	14.08
3.28	4	13.12
.0	1	0.00
		181.44
	× Common interval......	20 ft.
		3)3628.8
	Area required................	1209.6 sq. ft.

Rule B.

Simpson's Second Rule (to be used when the number of intervals is a multiple of 3). Add together the two end-

most breadths, twice every third intermediate breadth, and thrice each of the remaining intermediate breadths; multiply the sum by the common interval between the breadths, and by 3; divide the product by 8; the result will be the area required. Simpson's multipliers in this case are, for three intervals, 1, 3, 3, 1; for six intervals, 1, 3, 3, 2, 3, 3, 1; for nine intervals, 1, 3, 3, 2, 3, 3, 2, 3, 3, 1; and so on. *Example:* Length, 120 feet, divided into six intervals of 20 feet each.

Breadths in feet and Decimals.	Simpson's Multipliers.	Products.
17.28	1	17.28
16.40	3	49.20
14.08	3	42.24
10.80	2	21.60
7.04	3	21.12
3 28	3	9.84
.0	1	0.00
		161.28
	× Common interval......	20 ft.
		3225.6
		× 3
		8)9676.8
	Area required.................	1209.6 sq. ft.

Remarks.—The preceding examples are taken from a parabolic figure of the third degree, for which both "Simpson's Rules" are exact; and the results of using them agree together precisely. For other figures, for which the rules are approximate only, the first rule is in general somewhat more accurate than the second.

PROBLEMS IN RAILWAY CURVES.

Cant (elevation) *of Rails of Curves.*—Divide the square of the greatest ordinary speed of a train, by the radius of the curve and by a division whose values are as follows:

For speed in feet per second and radius in feet...32
For speed in miles per hour and radius in feet....15

Multiply the quotient by the gauge of the rails; the product will be the cant required in the same sort of measure with the gauge.

SETTING OUT CENTRE LINES OF RAILWAY CURVES.

To find the radius of a circular arc, fig. 33, which shall

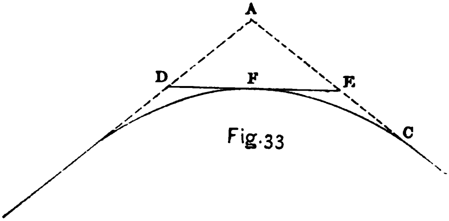


Fig. 33

touch successively three given straight lines *BB*, *DE*, *EC*. Measure the middle straight line *DE* and the *acute* angles at *D* and *E*. Then rad. $= D \div \left(\text{tang.}\ \frac{D}{2} + \text{tang.}\ \frac{E}{2}\right)$.

TO EASE CHANGES OF CURVATURE (FROUDE'S METHOD).

Begin by ranging the centre line. Calculate the cant of each curve as above; then

Rule 1.

Compute the several *changes of cant* at the junction of

curves with straight lines and with each other, observing that the change of cant between a straight line and a curve is simply the cant of the curve; that if two adjacent curves are curved in the same direction the change is the *difference* of cant, and that if they are curved in reverse directions the change is the sum of the two cants. Multiply the *greatest change of cant* by 300. The product will be the length of the *curve of adjustment.*

RULE 2.

Compute for each curve of the series the *shift* (throw of rail) as follows: Shift = (length of curve of adjustment)^2 ÷ 24 radius. Then shift the stakes by which a given curve is marked, inwards, (that is, towards the centre of curvature of the arc), through the distance computed by the above formula.

For example, in fig. 34, let AB, BC, be a pair of con-

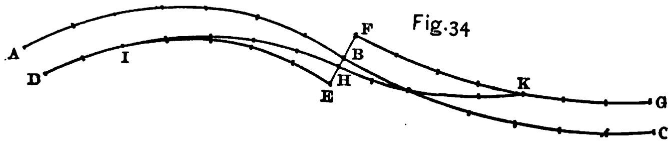


Fig. 34

secutive curves, marked by stakes, and joining each other at their point of contact B.

Let BE, BF, be the *shifts* proper to those two curves, respectively.

After all the stakes have been shifted they will mark the arcs DE, FG, having a gap between E F equal to the sum of the two shifts if the arcs are curved in reverse directions, or the difference of the shifts if the arcs are curved in the same direction. Straight lines are not to be shifted, so that where a curve joins a straight line the gap is simply the shift of the curve.

Rule 3.

Set out the "curve of adjustment" *IHK* as follows: For its middle point bisect the gap *E F* in *H*. For its ends *I* and *K* lay off *EI* and *FK*, each equal to half its length, as computed by Rule 1. For intermediate points in the division *IH*, lay off ordinates at right angles from a series of points in the curve *IE*, proportional to the cubes of the distances from *I*; and for intermediate points in the division *KH*, lay off ordinates at right angles from a series of points in the curve *KF*, proportional to the cubes of the distances from *K*. Let "a" denote the length *IK* of the curve of adjustment; "b," the gap *EF*, or some of the shifts; "x," the distance measured on the circular arc, of any point from *I* or *K*, as the case may be; the ordinate then $y = \frac{4bx^3}{a^3}$.

Example.—A curve of 1320 feet radius, with cant suited to a speed of 40 miles per hour, on a 4′ — 8½″ gauge line, is to be connected with a straight line.

Cant (see page 122) $= 500 \div 1320 = .3788$ foot.

Length of curve of adjustment "a" $= .3788 \times 300 =$ 113.6 feet.

Shift for circular arc $= (113.6)^2 \div 24 \times 1320 = .407$ ft.

(As the arc is to join a straight line, this is also $=$ the gap b.)

Formula for ordinates $y = \frac{4 \times .407x^3}{(113.6)^3} = .000.001.11x^3$.

Rule 4.

To connect a circular arc and a straight line, or two circular arcs which do not touch or cut each other, by means of a curve of adjustment. Fig. 34 illustrates the case where two arcs curved in reverse directions are to be connected; fig. 35, that in which two arcs curved in the same

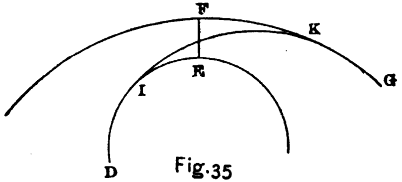


Fig. 35

direction are to be connected. Find the pair of points at which the arcs or lines to be connected are nearest to each other. This is best done by first finding two pairs of points at which the lines to be connected are at equal distances apart; the pair of points required will be midway between those two pair of points. Let E and F be the pair of points thus found; measure the *gap* EF, then calculate the *half length of the curve of adjustment* by means of the following formula, in which r and r' denote the radii of the arcs to be connected. $EI = FK = \sqrt{\left\{6EF \div \left(\frac{1}{r} \pm \frac{1}{r'}\right)\right\}}$, the sign $+$ or $-$ being used in the denominator according as the directions of curvature are reverse or similar. If one of the lines to be connected is straight, $\frac{1}{r}$ is to be made $= 0$, so that the formula becomes $EI = FK = \sqrt{6EF \times r}$.

The curve of adjustment is now to be set out by ordinates as in Rule 3.

CURVED WING-WALLS AND PROBLEMS IN CIRCULAR CURVES.

In drawing curved wing-walls to support an embanked approach to a bridge, the data given or assumed are the height bb', the inclination of the slope of the bank, which should coincide with that of the top of the wall, and the batter or slope of the face of the wall. To avoid confusing the diagram the coping of the wall is omitted. Let $bb' =$

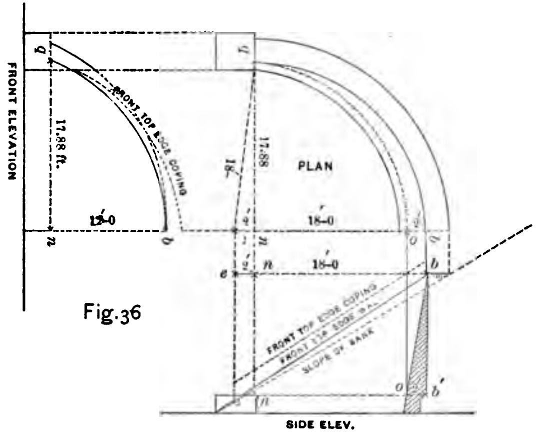


Fig.36

12 feet. Let the slope of the top of the wall be $1^1/_2$ horizontal to 1 vertical, then nob', $= 12$ ft. $\times$ $1^1/_2 = 18$ ft., and $en = ob'$, $= {}^{12}/_6$ ft. $= 2$ ft. Transfer these dimensions to the plan: $nb = eo = eq = 18$ ft.; $qn = \sqrt{nb^2 - en^2} = \sqrt{324 - 4} = 17.88$ ft.

The *plan* of the front line of the top of the wall will therefore be a quarter ellipse, whose semi-diameters are respectively 18 ft. and 17.88 ft.

The front elevation of the front line of the top of the wall will be a quarter ellipse of which the semi-diameters are respectively 12 ft. and 17.88 ft.

IN DESIGNING LARGE WORKS

It is often requisite to connect two straight lines by a circular curve. Before the offsets can be calculated for this purpose the following data must be known, viz.: the angle found by the lines to be connected; the radius of the curve; and the distance from the point of intersection to the points of contact.

The first of these conditions is generally known by the circumstances of the case. With regard to the second and third conditions, one of the two must be assumed and the other calculated from it.

THE DISTANCE OF THE POINTS OF CONTACT FROM THE POINT OF INTERSECTION BEING GIVEN, TO FIND THE RADIUS.

In the lines to be connected, let *b* and *d*, fig. 37, be the

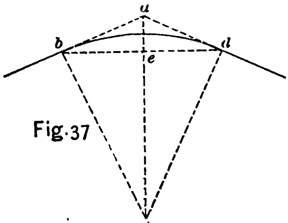


Fig. 37

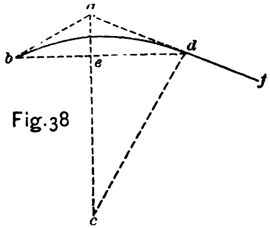


Fig. 38

points of contact, which will necessarily be equidistant from the point of intersection. Join *bd;* bisect it at *e*, and join *ae;* then radius $= \dfrac{be \times ab}{ae}$.

The construction made use of in the above problem is useful for determining the radius of curvature of a wing-wall of a bridge.

Thus, fig. 38, let *df* be the front of the bridge, *d* the point at which the curve is to commence, and *b* the point at which the wing-wall is to end. Join *bd;* bisect it at *e*, and erect the perpendicular *ea*, cutting *df* produced in *a;* join *ab*, and calculate the radius as above.

GIVEN THE SPAN AND RISE OF A CIRCULAR ARC TO FIND THE RADIUS.

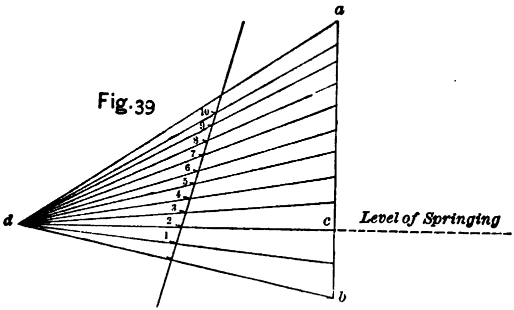
Let $r =$ radius, $s =$ half-span, $v =$ rise or versed sine, then $r = \dfrac{s^2 + v^2}{2v}$.

THE RADIUS BEING GIVEN, TO FIND THE LENGTH OF AN OFFSET AT ANY GIVEN POINT ON A TANGENT LINE.

Let $r =$ radius, $t =$ distance on tangent line from the point of contact, $o =$ offset, then $o = r - \sqrt{r^2 - t^2}$

TO DIVIDE A STRAIGHT LINE INTO A GIVEN NUMBER OF UNEQUAL PARTS, WHICH SHALL DIMINISH IN REGULAR PROGRESSION, AND SO THAT A GIVEN DIVISION SHALL PASS THROUGH A GIVEN POINT.

Let *ab*, fig. 39, be the height of the pier of a bridge which



it is proposed to divide into eleven quoins, the top of the second quoin being required to coincide with *c*, the level of the springing of the arch. Assume any convenient point *d*, and join *ad*, *cd*, *bd*. Take a slip of paper, divide its edge into eleven equal parts of convenient size, and slide it over the triangle until zero and the second division are respectively on the lines *bd*, *cd*, whilst the last division is on the line *ad*. Prick off the points 1, 3, 4, 5, 6, 7, 8, 9, 10, and draw lines through them, intersecting the line *ab*, which will then be divided as required.

THE AREA OF A CIRCULAR SECTOR

(*OACB*, fig. 40), is the same fraction of the whole circle,

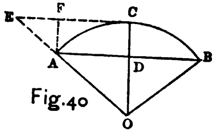


Fig. 40

that the angle *AOB* of the sector is of a whole revolution. In other words, multiply half the square of the radius, or one eighth of the square of the diameter, by the circular measure (to radius unity) of the angle *AOB*; the product will be the area of the sector.

A CIRCULAR SEGMENT

(*ADBC*, fig. 40), is equal to the sector *OACB*, less the triangle *OAB*. Hence, from the circular measure of the angle *AOB* subtract its sine; multiply the remainder by half the square of the radius; the product will be the area of the segment.

CIRCULAR SPANDRELS.

Case 1.

Spandrel *ACE*, bounded by the arc *AC*, the tangent *CE* and the external secant *AE*.

From the tangent of the angle AOC subtract the circular measure of that angle; multiply the remainder by half the square of the radius; the product will be the area.

Case 2.

Spandrel *ACF*, bounded by the arc *AC*, the tangent *CF*, and the straight line *AF* perpendicular to *CF*.

From twice the sine of the angle *AOC* subtract the circu-

lar measure of that angle and half the sine of double the angle; multiply the remainder by half the square of the radius; the product will be the area.

LENGTHS OF CURVES.

The Measurement of the Lengths of Curves—any Curve—by Chords.

Let AB, fig. 41, be the curve line whose length is to be

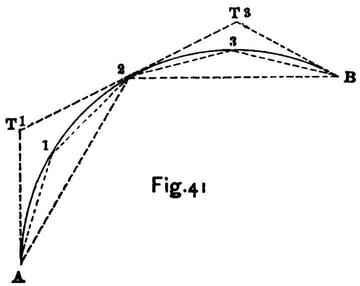


Fig.41

measured. Divide it into any *even* number of intervals, equal or unequal, by points (such as 1, 2, 3). Measure the series of straight chords (such as $\overline{A1}$, $\overline{12}$, $\overline{23}$, $\overline{3B}$), which span those intervals and take the sum of their lengths; measure also the straight chords (such as $\overline{A2}$, $\overline{2B}$), which span the intervals by pairs, and take the sum of their lengths; to the first sum add *one-third* of the difference between it and the second sum; the result will be the approximate length of the curve.

To Set out a Circular Curve of a given Radius r, touching two given Straight $\overline{AB}$, $\overline{AC}$, when the point of Intersection of those Lines A is Inaccessible.

Chain a straight line DE upon accessible ground, so as to

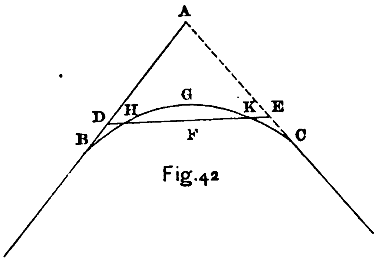


Fig.42

connect the two tangents. The position of the transversal, DE, is arbitrary; but it is convenient so to place it that it will cut the proposed curve in two points which may be determined and used as theodolite stations. Measure the angles ADE, AED, which may be denoted by D and E. Then the angle at A is, $A = 180° - D - E$; $AD = DE \frac{\text{sine } E}{\text{sine } A}$; $AE = DE \frac{\text{sin. } D}{\text{sin. } A}$; $DB = r$ cotang. $\frac{A}{2} - AD$; $EC = r$ cotang. $\frac{A}{2} - AE$; and by laying off the distances DB and EC, as thus calculated, the ends of the curve B and C are marked, and it can be ranged from either of those stations.

CHAINING ON A DECLIVITY. REDUCTION TO THE LEVEL.

The correction is always to be subtracted from the distance as measured. When the angle of inclination has been measured by a "clinometer" or other angular instrument:—

Correction in links per chain (66 ft.) $= 100 \times$ versed sine of inclination.

RULES FOR CONSTRUCTION OF MASONRY.

Stability of Abutments (including buttresses, abutments, and piers of arches, retaining and reservoir walls).

RULE.

To find the greatest deviation of the centre of pressure from the centre of figure, at any bed-joint, consistently with *stability of position* (that is, safety against overturning).

CASE 1.—*Retaining Walls.*

Greatest deviation of the centre of pressure from the centre of figure, as fixed by practical experience, = from 0.3 to 0.375 of the whole thickness of the wall at the given bed-joint.

RULE.

Given the load on a bed-joint and the position of the centre of pressure, to find approximately the intensity of the pressure at the edge to which the centre of pressure is nearest. In case of abutments and piers of arches, divide twice the load by the area of the bed; in Case 1, multiply the breadth of the bed by *once and a half* the distance of the centre of pressure from the nearest edge of the bed, and with a product as a divisor, divide the load; the quotient will be the required intensity. The intensity of pressure thus found ought not to exceed $^1/_8$ of the pressure which crushes the material of the building.

STONE AND BRICK ARCHES.

To find the least proper thickness for the arch-ring of a proposed arch.

Find the longest radius of curvature of the arch; then take a mean proportional between (that is, the square root of the product of) that radius and a constant whose values are as follows:

For an arch above ground standing solitary between its abutments,.................................. 0.12 ft.

For an arch forming one of a series of arches with piers between them,	0.17 ft.
For an underground archway in hard material (such as rock),	0.12 ft.
For an underground archway in gravel or firm earth,	0.27 ft.
For an underground archway in wet clay or quicksand,	0.48 ft.

To find the level up to which the backing of the arch should be built before the centre is struck.

Take a mean proportional between the radius of curvature of the intrados of the arch at its crown, and the thickness of the arch-ring; then lay off the length so calculated, vertically downwards from the crown of the outer surface of the arch-ring.

For a rough approximation to the horizontal thrust of an arch, take the weight of the vertical load that is supported between the crown of the arch, and that point in the arch-ring where its inclination to the horizon is 45°.

FACTORS OF SAFETY AND MODULI OF STRENGTH.

	Dead load.	Live load.
Factors of safety for perfect materials and workmanship,	2	4
Factors of safety for good ordinary materials and workmanship, to wit:		
Metals,	3	6
Timber,	4 to 5	8 to 10
Masonry,	4	8

A dead load on a structure is one that is put on by imperceptible degrees, and that remains steady; such as the weight of the structure itself. A *live load* is one that is put on sud-

denly or accompanied with vibrations; such as a swift train travelling over a railway bridge, or a force exerted in a moving machine.

Rule 1.

Given the proportions of live and dead load on a structure; to find the factor of safety for the mixed load.

Multiply the factor of safety for a dead load, by a number proportional to the dead part of the load, and the factor of safety for a live load, by the number proportional to the live part of the load; add together the products, and divide by the sum of the multipliers.

Example.—In an iron bridge, suppose dead load : live load : : 5 : 4; then $(3 \times 5) + (6 \times 4) = 39$; and $39 \div (5 + 4) = 4^1/_3$ = factor of safety for mixed load.

Rule 2.

Given the breaking load of a piece of material, to find the proof load.

Divide by the factor of safety for a dead load.

Rule 3.

Given the intended working load on a piece of material, to find the least proper breaking load.

Multiply by the proper factor of safety as found by Rule 1.

REDUCTION OF SOUNDINGS.

Take the difference between each sounding, and the height of the surface of the water above the datum of the survey at the instant when the sounding was made, as found by a tide register. According as the sounding is the $\left\{ \begin{matrix} \text{greater} \\ \text{less} \end{matrix} \right\}$ that difference is the $\left\{ \begin{matrix} \text{depth} \\ \text{height} \end{matrix} \right\}$ of the bottom

$\left\{\begin{matrix}\text{below}\\ \text{above}\end{matrix}\right\}$ the datum. In the absence of direct observations of the tide, the height of the surface of the water above the datum may be calculated approximately as follows: Divide the time before or after high water at which the sounding was taken, by the whole duration of the rise or fall of the tide, and multiply the quotient by 180°; this gives the *tidal angle.*

Multiply the cosine of the tidal angle by half the total rise of the tide; the product is to be $\left\{\begin{matrix}\text{added to}\\ \text{subtracted from}\end{matrix}\right\}$ the height of the mean tide-level above the datum, according as the tidal angle is $\left\{\begin{matrix}\text{acute}\\ \text{obtuse.}\end{matrix}\right\}$

DAY'S WORK OF A MAN REQUIRED FOR VARIOUS OPERATIONS. DAY = 10 HOURS.

Shovelling earth, 1 cub. yd. thrown not more than 5 ft. vertically up, if dry,..............	.05 to .0625
Shovelling earth, wet mud, ...	.06 to .08
Excavating earth with the pick. 1 cub. yd.....	.025 to .02
Wheeling 1 cub. yd. earth in barrows from 100 to 200 feet horizontally. If up a slope at the same time deduct 6 feet from the horizontal dist. for each foot of rise,...	.05 to .0625
Spreading and ramming earth in layers from 9 to 18 inches deep. 1 cub. yd.,......	.06 to .07
Dressing slopes of cuttings. 1sq. yd............	about .008
Making clay puddle. 1 cub. yd.,..................	.3
Spreading " "	.3
Quarrying rock of moderate hardness. 1 cub. yd. av.,.......	.4
Jumping holes in rock. 100 cylindrical inches, granite,........	1.0 to 0.5

Jumping holes in rock. 100 cylindrical inches, limestone,.......	.2 to .15
Quarrying rock in tunnels. 1 cub. yd...........	.75 to 3.
Mixing mortar by hand. "	.75
Mixing concrete, wheeling and laying. 1 cub. yd.	.3
Loading barrows with stone....... .... " "	.06
Wheeling 1 cub. yd. stone 100 ft. horizontally. If an ascent, allow 6 feet of distance for each foot of rise,...........................	0.45
Unloading barrows of stone. 1 cub. yd.........	.03

Stone Masonry. 1 cub. yd.	Breaking Stone.	Cutting Stone.	Building.	Laborers' Work.
Dry stone,...........	.64		1.00	.50
Coursed rubble, ...	.64		.90	.90
Block-in-course,.....	.90	1.5	.90	.90
Block arching,......	.90	2.25	.90	.90
Ashlar Sandstone } soft { from	1.80	2.50	1.00	1.00
Ashlar Sandstone } soft { to....	2.5	6.00	2.00	2.00

Taking down old masonry,...... 1 cub. yd. .5 to 6

		Carpenter.	Laborer.
Erecting centres for arches, per 100 sq. feet area of soffit,	from	1.75	.75
	to..........	1.70	.80

TABLE OF FRICTION OF PLANE SURFACES WHEN THEY HAVE BEEN SOME TIME IN CONTACT.

Surfaces in contact.	Disposition of fibres.	Co-efficient of friction.	Limiting angle of Resistance.
Oak upon oak...........	parallel,	0.62	31° 48′
Oak upon Elm..........	"	0.38	20° 49′
Elm upon oak..........	"	0.69	34° 37′
Hard calcareous stone upon hard calcareous stone...............	flat,	0.70	35°

NATURE OF BODIES.

	Co-efficient of Friction.	Limiting angle of Resistance.
Soft calcareous stone, well dressed, upon the same	0.74	36° 30′
Hard calcareous stone, well dressed, upon the same	0.75	36° 52′
Common brick upon the same	0.67	33° 50′
Calcareous stone upon the same, both surfaces being made rough	0.78	37° 58′

TABLES.

Angle.	Arc.	Sine.	Tang.	Co-Tang.	Co-Sine.
1°	01745	01745	01746	57.28996	99985
2	03491	03490	03492	28.63625	99939
3	05236	05234	05241	19.08114	99863
4	06981	06976	06993	14.30067	99756
5	08727	08716	08749	11.43005	99619
6	10472	10453	10510	9.51436	99452
7	12217	12187	12278	8.14435	99255
8	13963	13917	14054	7.11540	99027
9	15708	15643	15838	6.31375	98769
10	17453	17365	17633	5.67128	98481
11	19199	19081	19438	5.14455	98163
12	20944	20791	21256	4.70463	97815
13	22689	22495	23087	4.33148	97437
14	24435	24192	24933	4.01078	97030
15	26180	25882	26795	3.73205	96593
16	27925	27564	28675	3.48741	96126
17	29671	29237	30573	3.27085	95630
18	31416	30902	32492	3.07768	95106
19	33161	32557	34433	2.90421	94552
20	34907	34202	36397	2.74748	93969

MINUTE OF PRIME VERTICAL (being the great Circle Perpendicular to the Meridian) in feet $= \dfrac{12214 + \text{Length of Minute of Meridian}}{3}$.

Lat.	Min. Long.	Min. Pr. V.	Min. Lat.	Min. Lat.	Min. Pr. V.	Min. Long.	Lat.
0°	6086	6086	6045	6066	6093	4930	36°
1	6085	6086	6045	6067	6094	4867	37
2	6083	6086	6045	6068	6094	4802	38
3	6078	6086	6045	6070	6095	4736	39
4	6071	6086	6045	6071	6095	4669	40
5	6063	6086	6045	6072	6095	4600	41
6	6053	6087	6046	6073	6096	4530	42
7	6041	6087	6046	6074	6096	4458	43
8	6027	6087	6046	6075	6096	4385	44
9	6012	6087	6047	6076	6097	4311	45
10	5994	6087	6047	6077	6097	4235	46
11	5975	6087	6047	6078	6097	4158	47
12	5954	6087	6048	6079	6098	4080	48
13	5931	6087	6048	6080	6098	4001	49
14	5907	6088	6049	6081	6098	3920	50
15	5880	6088	6049	6082	6099	3838	51
16	5852	6088	6050	6084	6099	3755	52
17	5822	6088	6050	6085	6100	3671	53
18	5790	6088	6051	6086	6100	3586	54
19	5757	6089	6052	6087	6100	3499	55
20	5721	6089	6052	6088	6101	3413	56
21	5684	6089	6053	6089	6101	3323	57
22	5646	6089	6054	6090	6101	3233	58
23	5605	6089	6054	6091	6102	3142	59
24	5563	6090	6055	6091	6102	3051	60
25	5519	6090	6056	6092	6102	2958	61
26	5474	6090	6057	6093	6102	2865	62
27	5427	6091	6058	6094	6103	2771	63
28	5378	6091	6059				
29	5327	6091	6060	6096	6103	2579	65
30	5275	6092	6061	6100	6105	2088	70
31	5222	6092	6061	6103	6106	1580	75
32	5166	6092	6062	6105	6106	1060	80
33	5109	6092	6063	6107	6107	532	85
34	5051	6093	6064	6107	6107	0	90
35	4991	6093	6065				

Rogers' Geology of Pennsylvania.

3 Vols. 4to, with Portfolio of Maps. Cloth. $30.00.

THE GEOLOGY OF PENNSYLVANIA. A Government Survey. With a general view of the Geology of the United States, Essays on the Coal Formation and its Fossils, and a description of the Coal Fields of North America and Great Britain. By HENRY DARWIN ROGERS, Late State Geologist of Pennsylvania. Splendidly illustrated with Plates and Engravings in the Text

Merrill's Iron Truss Bridges.

Third Edition. 4to. Cloth. $5.00.

IRON TRUSS BRIDGES FOR RAILROADS. The Method of Calculating Strains in Trusses, with a careful comparison of the most prominent Trusses, in reference to economy in combination, etc., etc. By Bvt. Col. WILLIAM E. MERRILL, U.S.A., Corps of Engineers. Nine lithographed plates of illustrations.

Shreve on Bridges and Roofs.

8vo, 87 wood-cut illustrations. Cloth. $5.00.

A TREATISE ON THE STRENGTH OF BRIDGES AND ROOFS—comprising the determination of Algebraic formulas for Strains in Horizontal, Inclined or Rafter, Triangular, Bowstring, Lenticular and other Trusses, from fixed and moving loads, with practical applications and examples, for the use of Students and Engineers. By Samuel H. Shreve, A. M., Civil Engineer.

The Kansas City Bridge.

4to. Cloth. $6.00

WITH AN ACCOUNT OF THE REGIMEN OF THE MISSOURI RIVER,—and a description of the Methods used for Founding in that River. By O. Chanute, Chief Engineer, and George Morison, Assistant Engineer. Illustrated with five lithographic views and twelve plates of plans.

Clarke's Quincy Bridge.

4to. Cloth. $7.50.

DESCRIPTION OF THE IRON RAILWAY. Bridge across the Mississippi River at Quincy, Illinois. By Thomas Curtis Clarke, Chief Engineer. With twenty-one lithographed plans.

Whipple on Bridge Building.

New edition. 8vo. Illustrated. Cloth. $4.

An Elementary and Practical Treatise on Bridge Building. By S. Whipple, C. E.

Roebling's Bridges.

Imperial folio. Cloth. $25.00.

Long and Short Span Railway Bridges. By John A. Roebling, C. E. With large copperplate engravings of plans and views.

Dubois' Graphical Statics.

8vo. 60 Illustrations. Cloth. $2.00.

The New Method of Graphical Statics. By A. J. Dubois, C. E., Ph. D.

Greene's Bridge Trusses.

8vo. Illustrated. Cloth. $2.00.

Graphical Method for the Analysis of Bridge Trusses,—extended to Continuous Girders and Draw Spans. By Charles E. Greene, A. M., Professor of Civil Engineering, University of Michigan. Illustrated by three folding plates.

Bow on Bracing.

156 Illustrations on Stone. 8vo. Cloth. $1.50.

A Treatise on Bracing,—with its application to Bridges and other Structures of Wood or Iron. By Robert Henry Bow, C. E.

Stoney on Strains.

New and Revised Edition, with numerous illustrations. Royal 8vo, 664 pp. Cloth. $12.50.

The Theory of Strains in Girders—and Similar Structures, with Observations on the Application of Theory to Practice, and Tables of Strength and other Properties of Materials. By Bindon B. Stoney, B. A.

Henrici's Skeleton Structures.

8vo. Cloth. $1.50.

Skeleton Structures, especially in their Application to the building of Steel and Iron Bridges. By Olaus Henrici.

Burgh's Modern Marine Engineering.

One thick 4to vol. Cloth. . $25.00. Half morocco. $30.00.

MODERN MARINE ENGINEERING, applied to Paddle and Screw Propulsion. Consisting of 36 Colored Plates, 259 Practical Wood-cut Illustrations, and 403 pages of Descriptive Matter, the whole being an exposition of the present practice of the following firms: Messrs. J. Penn & Sons; Messrs. Maudslay, Sons & Field ; Messrs. James Watt & Co. ; Messrs. J. & G. Rennie; Messrs. R. Napier & Sons; Messrs. J. & W. Dudgeon ; Messrs. Ravenhill & Hodgson; Messrs. Humphreys & Tenant; Mr. J. T. Spencer, and Messrs. Forrester & Co. By N. P. BURGH, Engineer.

King's Notes on Steam.

Nineteenth Edition. 8vo. $2.00.

LESSONS AND PRACTICAL NOTES ON STEAM,—the Steam Engine, Propellers, &c., &c., for Young Engineers. By the late W. R. KING, U. S. N. Revised by Chief-Engineer J. W. KING, U. S. Navy.

Link and Valve Motions, by W. S. Auchincloss.

Sixth Edition. 8vo. Cloth. $3.00.

APPLICATION OF THE SLIDE VALVE and Link Motion to Stationary, Portable, Locomotive and Marine Engines. By WILLIAM S. AUCHINCLOSS. Designed as a hand-book for Mechanical Engineers. Dimensions of the valve are found by means of a Printed Scale, and proportions of the link determined *without* the assistance of a model. With 37 wood-cuts and 21 lithographic plates, with copperplate engraving of the Travel Scale.

Bacon's Steam-Engine Indicator.

12mo. Cloth. $1.00 Mor. $1.50.

A TREATISE ON THE RICHARDS STEAM-ENGINE INDICATOR,—with directions for its use. By CHARLES T. PORTER. Revised, with notes and large additions as developed by American Practice, with an Appendix containing useful formulæ and rules for Engineers. By F. W. BACON, M. E., Illustrated. Second Edition.

Isherwood's Engineering Precedents.

Two Vols. in One. 8vo. Cloth. $2.50.

ENGINEERING PRECEDENTS FOR STEAM MACHINERY.—By B. F. ISHERWOOD, Chief Engineer, U. S. Navy. With illustrations.

Slide Valve by Eccentrics, by Prof. C. W. MacCord.

4to. Illustrated. Cloth, $3.00

A PRACTICAL TREATISE ON THE SLIDE VALVE BY ECCENTRICS,—examining by methods the action of the Eccentric upon the Slide Valve, and explaining the practical processes of laying out the movements, adapting the valve for its various duties in the steam-engine. For the use of Engineers, Draughtsmen, Machinists, and Students of valve motions in general. By C. W. MACCORD, A. M., Professor of Mechanical Drawing, Stevens' Institute of Technology, Hoboken, N. J.

Stillman's Steam-Engine Indicator.

12mo. Cloth. $1.00

THE STEAM-ENGINE INDICATOR,—and the Improved Manometer Steam and Vacuum Gauges; their utility and application. By PAUL STILLMAN. New edition.

Porter's Steam-Engine Indicator.

Third Edition. Revised and Enlarged. 8vo. Illustrated. Cloth. $3.50.

A TREATISE ON THE RICHARDS STEAM-ENGINE INDICATOR,—and the Development and Application of Force in the Steam-Engine. By CHARLES T. PORTER.

McCulloch's Theory of Heat.

8vo. Cloth. $3.50.

A TREATISE ON THE MECHANICAL THEORY OF HEAT, AND ITS APPLICATIONS TO THE STEAM-ENGINE. By Prof. R. S. MCCULLOCH, of the Washington and Lee University, Lexington, Va.

Van Buren's Formulas.

8vo. Cloth. $2.00.

INVESTIGATIONS OF FORMULAS,—for the Strength of the Iron parts of Steam Machinery. By J. D. VAN BUREN, Jr., C. E. Illustrated.

Stuart's Successful Engineer.

18mo. Boards. 50 cents.

HOW TO BECOME A SUCCESSFUL ENGINEER. Being Hints to Youths intending to adopt the Profession. By BERNARD STUART, Engineer. Sixth Edition.

Stuart's Naval Dry Docks.

Twenty-four engravings on steel. Fourth edition. 4to. Cloth. $6.00.

THE NAVAL DRY DOCKS OF THE UNITED STATES. By CHARLES B. STUART, Engineer in Chief U. S. Navy.

Ward's Steam for the Million.

8vo. Cloth. $1.00.

STEAM FOR THE MILLION. A Popular Treatise on Steam and its Application to the Useful Arts, especially to Navigation. By J. H. WARD, Commander U. S. Navy.

Tunner on Roll-Turning.

1 vol. 8vo. and 1 vol. folio plates. $10.00.

A TREATISE ON ROLL-TURNING FOR THE MANUFACTURE OF IRON, by PETER TUNNER. Translated by JOHN B. PEARSE, of the Pennsylvania Steel Works. With numerous wood-cuts, 8vo., together with a folio atlas of 10 lithographed plates of Rolls, Measurements, &c.

Grüner on Steel.

8vo. Cloth. $3.50.

THE MANUFACTURE OF STEEL. By M. L. GRÜNER; translated from the French. By LENOX SMITH, A.M., E.M.; with an Appendix on the Bessemer Process in the United States, by the translator. Illustrated by lithographed drawings and wood-cuts.

Barba on the Use of Steel.

12mo. Illustrated. Cloth. $1.50.

THE USE OF STEEL IN CONSTRUCTION. Methods of Working, Applying, and Testing Plates and Bars. By J. BARBA, Chief Naval Constructor. Translated from the French, with a Preface, by A. L. HOLLEY, P.B.

Bell on Iron Smelting.

8vo. Cloth. $6.00.

CHEMICAL PHENOMENA OF IRON SMELTING. An experimental and practical examination of the circumstances which determine the capacity of the Blast Furnace, the Temperature of the Air, and the Proper Condition of the Materials to be operated upon. By I. LOWTHIAN BELL.

The Useful Metals and their Alloys; Scoffren, Truran, and others.

Fifth Edition. 8vo. Half calf. $3.75.

THE USEFUL METALS AND THEIR ALLOYS, employed in the conversion of IRON, COPPER, TIN, ZINC, ANTIMONY, AND LEAD ORES, with their applications to the INDUSTRIAL ARTS. By JOHN SCOFFREN, WILLIAM TRURAN, WILLIAM CLAY, ROBERT OXLAND, WILLIAM FAIRBAIRN, W. C. AITKIN, and WILLIAM VOSE PICKETT.

Collins' Useful Alloys.

18mo. Flexible. 75 cents.

THE PRIVATE BOOK OF USEFUL ALLOYS and Memoranda for Goldsmiths, Jewellers, etc. By JAMES E. COLLINS.

Joynson's Metal Used in Construction.

12mo. Cloth. 75 cents.

THE METALS USED IN CONSTRUCTION: Iron, Steel, Bessemer Metal, etc., etc. By FRANCIS H. JOYNSON. Illustrated.

Dodd's Dictionary of Manufactures, etc.

12mo. Cloth. $1.50.

DICTIONARY OF MANUFACTURES, MINING, MACHINERY, AND THE INDUSTRIAL ARTS. By GEORGE DODD.

Von Cotta's Ore Deposits.

8vo. Cloth. $4.00.

TREATISE ON ORE DEPOSITS. By BERNHARD VON COTTA, Professor of Geology in the Royal School of Mines, Freidburg, Saxony. Translated from the second German edition, by FREDERICK PRIME, Jr., Mining Engineer, and revised by the author; with numerous illustrations.

Plattner's Blow-Pipe Analysis.

Third Edition. Revised. 568 pages. 8vo. Cloth. $5.00.

PLATTNER'S MANUAL OF QUALITATIVE AND QUANTITATIVE ANALYSIS WITH THE BLOW-PIPE. From the last German edition, Revised and enlarged. By Prof. TH. RICHTER, of the Royal Saxon Mining Academy. Translated by Professor H. B. CORNWALL; assisted by JOHN H. CASWELL. With eighty-seven wood-cuts and Lithographic Plate.

Plympton's Blow-Pipe Analysis.

12mo. Cloth. $1.50.

THE BLOW-PIPE: A Guide to its Use in the Determination of Salts and Minerals. Compiled from various sources, by GEORGE W. PLYMPTON, C.E., A.M., Professor of Physical Science in the Polytechnic Institute, Brooklyn, N.Y.

Pynchon's Chemical Physics.

New Edition. Revised and enlarged. Crown 8vo. Cloth. $3.00.

INTRODUCTION TO CHEMICAL PHYSICS; Designed for the Use of Academies, Colleges, and High Schools. Illustrated with numerous engravings, and containing copious experiments, with directions for preparing them. By THOMAS RUGGLES PYNCHON, M.A., President of Trinity College, Hartford.

Eliot and Storer's Qualitative Chemical Analysis.

New Edition. Revised. 12mo. Illustrated. Cloth. $1.50.

A COMPENDIOUS MANUAL OF QUALITATIVE CHEMICAL ANALYSIS. By CHARLES W. ELIOT and FRANK H. STORER. Revised, with the coöperation of the Authors, by WILLIAM RIPLEY NICHOLS, Professor of Chemistry in the Massachusetts Institute of Technology.

Rammelsberg's Chemical Analysis.

8vo. Cloth. $2.25.

GUIDE TO A COURSE OF QUANTITATIVE CHEMICAL ANALYSIS, ESPECIALLY OF MINERALS AND FURNACE PRODUCTS. Illustrated by Examples. By C. F. RAMMELSBERG. Translated by J. TOWLER, M.D.

Naquet's Legal Chemistry.

Illustrated. 12mo. Cloth. $2.00.

LEGAL CHEMISTRY. A Guide to the Detection of Poisons, Falsification of Writings, Adulteration of Alimentary and Pharmaceutical Substances; Analysis of Ashes, and Examination of Hair, Coins, Fire-arms, and Stains, as Applied to Chemical Jurisprudence. For the Use of Chemists, Physicians, Lawyers, Pharmacists, and Experts. Translated, with additions, including a List of Books and Memoirs on Toxicology, etc., from the French of A. NAQUET. By J. P. BATTERSHALL, Ph. D., with a Preface by C. F. CHANDLER, Ph. D., M.D., LL.D

Prescott's Proximate Organic Analysis.

12mo. Cloth. $1.75.

OUTLINES OF PROXIMATE ORGANIC ANALYSIS, for the Identification, Separation, and Quantitative Determination of the more commonly occurring Organic Compounds. By ALBERT B. PRESCOTT, Professor of Organic and Applied Chemistry in the University of Michigan.

Prescott's Alcoholic Liquors.

12mo. Cloth. $1.50.

CHEMICAL EXAMINATION OF ALCOHOLIC LIQUORS.—A Manual of the Constituents of the Distilled Spirits and Fermented Liquors of Commerce, and their Qualitative and Quantitative Determinations. By ALBERT B. PRESCOTT, Professor of Organic and Applied Chemistry in the University of Michigan.

Pope's Modern Practice of the Electric Telegraph.

Ninth Edition. 8vo. Cloth. $2.00.

A Hand-book for Electricians and Operators. By FRANK L. POPE. Ninth edition. Revised and enlarged, and fully illustrated.

Sabine's History of the Telegraph.

Second Edition. 12mo. Cloth. $1.25.

HISTORY AND PROGRESS OF THE ELECTRIC TELEGRAPH, with Descriptions of some of the Apparatus. By ROBERT SABINE, C.E.

Haskins' Galvanometer.

Pocket form. Illustrated. Morocco tucks. $2.00.

THE GALVANOMETER, AND ITS USES;—A Manual for Electricians and Students. By C. H. HASKINS.

Myer's Manual of Signals.

New Edition. Enlarged. 12mo. 48 Plates, full Roan. $5.00.

MANUAL OF SIGNALS, for the Use of Signal Officers in the Field. By Brig.-Gen. ALBERT J. MYER, Chief Signal Officer of the Army.

Larrabee's Secret Letter and Telegraph

18mo. Cloth. $1.00.

CIPHER AND SECRET LETTER AND TELEGRAPHIC CODE, with Hogg's Improvements. By C. S. LARRABEE.

Gillmore's Limes and Cements.

Fifth Edition. Revised and Enlarged. 8vo. Cloth. $4.00.

PRACTICAL TREATISE ON LIMES, HYDRAULIC CEMENTS, AND MORTARS. By Q. A. GILLMORE, Lt.-Col. U. S. Corps of Engineers. Brevet Major-General U. S. Army.

Gillmore's Coignet Beton.

Nine Plates, Views, etc. 8vo. Cloth. $2.50.

COIGNET BETON AND OTHER ARTIFICIAL STONE.—By Q. A. GILLMORE, Lt.-Col. U. S. Corps of Engineers, Brevet Major-General U.S. Army.

Gillmore on Roads.

Seventy Illustrations. 12mo. Cloth. $2.00.

A PRACTICAL TREATISE ON THE CONSTRUCTION OF ROADS, STREETS, AND PAVEMENTS. By Q. A. GILLMORE, Lt.-Col. U. S. Corps of Engineers, Brevet Major-General U. S. Army.

Gillmore's Building Stones.

8vo. Cloth. $1.50.

REPORT ON STRENGTH OF THE BUILDING STONES IN THE UNITED STATES, etc.

Holley's Railway Practice.

1 vol. folio. Cloth. $12.00.

AMERICAN AND EUROPEAN RAILWAY PRACTICE, in the Economical Generation of Steam, including the materials and construction of Coal-burning Boilers, Combustion, the Variable Blast, Vaporization, Circulation, Super-heating, Supplying and Heating Feed-water, &c., and the adaptation of Wood and Coke-burning Engines to Coal-burning; and in Permanent Way, including Road-bed, Sleepers, Rails, Joint Fastenings, Street Railways, etc., etc. By ALEXANDER L. HOLLEY, B.P. With 77 lithographed plates.

Useful Information for Railway Men.

Pocket form. Morocco, gilt. $2.00.

Compiled by W. G. HAMILTON, Engineer. Sixth Edition, Revised and Enlarged. 570 pages.

Stuart's Civil and Military Engineering of America.

8vo. Illustrated. Cloth. $5.00.

THE CIVIL AND MILITARY ENGINEERS OF AMERICA. By General CHARLES B. STUART, Author of "Naval Dry Docks of the United States," etc., etc. Embellished with nine finely-executed Portraits on steel of eminent Engineers, and illustrated by Engravings of some of the most important and original works constructed in America.

Ernst's Manual of Military Engineering.

193 Wood-cuts and 3 Lithographed Plates. 12mo. Cloth. $5.00

A MANUAL OF PRACTICAL MILITARY ENGINEERING. Prepared for the use of the Cadets of the U. S. Military Academy, and for Engineer Troops. By Capt. O. H. ERNST, Corps of Engineers, Instructor in Practical Military Engineering, U. S. Military Academy.

Simms' Levelling.

12mo. Cloth. $2.50.

A TREATISE ON THE PRINCIPLES AND PRACTICE OF LEVELLING, showing its application to purposes of Railway Engineering and the Construction of Roads, etc. By FREDERICK W. SIMMS, C.E. From the fifth London edition, Revised and Corrected, with the addition of Mr. Law's Practical Examples for Setting-out Railway Curves. Illustrated with three lithographic plates and numerous wood-cuts.

Jeffers' Nautical Surveying.

Illustrated with 9 Copperplates and 31 Wood-cut Illustrations. 8vo. Cloth. $5.00.

NAUTICAL SURVEYING. By WILLIAM N. JEFFERS, Captain U. S. Navy.

Brunnow's Spherical Astronomy.

Illustrated. 8vo. Cloth. $6.50.

SPHERICAL ASTRONOMY. By F. BRUNNOW, Ph. Dr. Translated by the Author from the second German edition.

The Plane Table.

8vo. Cloth. $2.00.

ITS USES IN TOPOGRAPHICAL SURVEYING. From the papers of the U. S. Coast Survey.

Chauvenet's Lunar Distances.

8vo. Cloth. $2.00.

NEW METHOD OF CORRECTING LUNAR DISTANCES, and Improved Method of Finding the Error and Rate of a Chronometer, by equal altitudes. By WM. CHAUVENET, LL.D., Chancellor of Washington University of St. Louis.

Burt's Key to Solar Compass.

Second Edition. Pocket-book form. Tuck. $2.50.

KEY TO THE SOLAR COMPASS, and Surveyor's Companion; comprising all the Rules necessary for use in the Field; also Description of the Linear Surveys and Public Land System of the United States, Notes on the Barometer, Suggestions for an Outfit for a Survey of Four Months, etc. By W. A. BURT, U. S. Deputy Surveyor.

Howard's Earthwork Mensuration.

8vo. Illustrated. Cloth. $1.50.

EARTHWORK MENSURATION ON THE BASIS OF THE PRISMOIDAL FORMULÆ. Containing simple and labor-saving method of obtaining Prismoidal Contents directly from End Areas. Illustrated by Examples, and accompanied by Plain Rules for practical uses. By CONWAY R. HOWARD, Civil Engineer, Richmond, Va.

Morris' Easy Rules.

78 Illustrations. 8vo. Cloth. $1.50.

EASY RULES FOR THE MEASUREMENT OF EARTHWORKS, by means of the Prismoidal Formula. By ELWOOD MORRIS, Civil Engineer.

Clevenger's Surveying.

Illustrated Pocket Form. Morocco, gilt. $2.50.

A TREATISE ON THE METHOD OF GOVERNMENT SURVEYING, as prescribed by the U. S. Congress and Commissioner of the General Land Office. With complete Mathematical, Astronomical, and Practical Instructions for the use of the U. S. Surveyors in the Field, and Students who contemplate engaging in the business of Public Land Surveying. By S. V. CLEVENGER, U. S. Deputy Surveyor.

Hewson on Embankments.

8vo. Cloth. $2.00.

PRINCIPLES AND PRACTICE OF EMBANKING LANDS from River Floods, as applied to the Levees of the Mississippi. By WILLIAM HEWSON, Civil Engineer.

Minifie's Mechanical Drawing.

Ninth Edition. Royal 8vo. Cloth. $4.00.

A TEXT-BOOK OF GEOMETRICAL DRAWING, for the use of Mechanics and Schools. With illustrations for Drawing Plans, Sections, and Elevations of Buildings and Machinery ; an Introduction to Isometrical Drawing, and an Essay on Linear Perspective and Shadows. With over 200 diagrams on steel. By WILLIAM MINIFIE, Architect. With an Appendix on the Theory and Application of Colors.

Minifie's Geometrical Drawing.

New Edition. Enlarged. 12mo. Cloth. $2.00.

GEOMETRICAL DRAWING. Abridged from the octavo edition, for the use of Schools. Illustrated with 48 steel plates.

Free Hand Drawing.

Profusely Illustrated. 18mo. Boards. 50 cents.

A GUIDE TO ORNAMENTAL, Figure, and Landscape Drawing. By an Art Student.

The Mechanic's Friend.

12mo. Cloth. 300 Illustrations. $1.50.

THE MECHANIC'S FRIEND. A Collection of Receipts and Practical Suggestions, relating to Aquaria—Bronzing—Cements—Drawing—Dyes—Electricity—Gilding—Glass-working—Glues—Horology—Lacquers—Locomotives—Magnetism—Metal-working—Modelling—Photography—Pyrotechny—Railways — Solders — Steam-Engine — Telegraphy—Taxidermy—Varnishes—Waterproofing—and Miscellaneous Tools, Instruments, Machines, and Processes connected with the Chemical and Mechanical Arts. By WILLIAM E. AXON, M.R.S.L.

Harrison's Mechanic's Tool-Book.

44 Illustrations. 12mo. Cloth. $1.50.

MECHANICS' TOOL BOOK, with Practical Rules and Suggestions, for the use of Machinists, Iron Workers, and others. By W. B. HARRISON.

Randall's Quartz Operator's Hand-Book.

12mo. Cloth. $2.00.

QUARTZ OPERATOR'S HAND-BOOK. By P. M. RANDALL. New edition, Revised and Enlarged. Fully illustrated.

Joynson on Machine Gearing.

8vo. Cloth. $2.00.

THE MECHANIC'S AND STUDENT'S GUIDE in the designing and Construction of General Machine Gearing, as Eccentrics, Screws, Toothed Wheels, etc., and the Drawing of Rectilineal and Curved Surfaces. Edited by FRANCIS H. JOYNSON. With 18 folded plates.

Silversmith's Hand-Book.

Fourth Edition. Illustrated. 12mo. Cloth. $3.00.

A PRACTICAL HAND-BOOK FOR MINERS, Metallurgists, and Assayers. By JULIUS SILVERSMITH. Illustrated.

Barnes' Submarine Warfare.

8vo. Cloth. $5.00.

SUBMARINE WARFARE, DEFENSIVE AND OFFENSIVE. Descriptions of the various forms of Torpedoes, Submarine Batteries and Torpedo Boats actually used in War. Methods of Ignition by Machinery, Contact Fuzes, and Electricity, and a full account of experiments made to determine the Explosive Force of Gunpowder under Water. Also a discussion of the Offensive Torpedo system, its effect upon Iron-clad Ship systems, and influence upon future Naval Wars. By Lieut.-Com. JOHN S. BARNES, U.S.N. With twenty lithographic plates and many wood-cuts.

Foster's Submarine Blasting.

4to. Cloth. $3.50.

SUBMARINE BLASTING, in Boston Harbor, Massachusetts—Removal of Tower and Corwin Rocks. By JOHN G. FOSTER, U. S. Eng. and Bvt. Major-General U. S. Army. With seven plates.

Mowbray's Tri-Nitro-Glycerine.

8vo. Cloth. Illustrated. $3.00

TRI-NITRO-GLYCERINE, as applied in the Hoosac Tunnel, and to Submarine Blasting, Torpedoes, Quarrying, etc.

Williamson on the Barometer.

4to. Cloth. $15.00.

ON THE USE OF THE BAROMETER ON SURVEYS AND RECONNAISSANCES. Part I.—Meteorology in its Connection with Hypsometry. Part II.—Barometric Hypsometry. By R. S. WILLIAMSON, Bvt. Lt.-Col. U. S. A., Major Corps of Engineers. With illustrative tables and engravings.

Williamson's Meteorological Tables.

4to. Flexible Cloth. $2.50.

PRACTICAL TABLES IN METEOROLOGY AND HYPSOMETRY, in connection with the use of the Barometer. By Col. R. S. WILLIAMSON, U.S.A.

Butler's Projectiles and Rifled Cannon.

4to. 36 Plates. Cloth. $7.50.

PROJECTILES AND RIFLED CANNON. A Critical Discussion of the Principal Systems of Rifling and Projectiles, with Practical Suggestions for their Improvement. By Capt. JOHN S. BUTLER, Ordnance Corps, U. S. A.

Benét's Chronoscope.

Second Edition. Illustrated. 4to. Cloth. $3.00.

ELECTRO-BALLISTIC MACHINES, and the Schultz Chronoscope. By Lt.-Col. S. V. BENÉT, Chief of Ordnance U. S. A.

Michaelis' Chronograph.

4to. Illustrated. Cloth. $3.00.

THE LE BOULENGÉ CHRONOGRAPH. With three lithographed folding plates of illustrations. By Bvt. Captain O. E. MICHAELIS, Ordnance Corps, U. S. A.

Nugent on Optics.

12mo. Cloth. $1.50.

TREATISE ON OPTICS; or, Light and Sight, theoretically and practically treated; with the application to Fine Art and Industrial Pursuits. By E. NUGENT. With 103 illustrations.

Peirce's Analytic Mechanics.

4to. Cloth. $10.00.

SYSTEM OF ANALYTIC MECHANICS. By BENJAMIN PEIRCE, Professor of Astronomy and Mathematics in Harvard University.

Craig's Decimal System.

Square 32mo. Limp. 50c.

WEIGHTS AND MEASURES. An Account of the Decimal System, with Tables of Conversion for Commercial and Scientific Uses. By B. F. CRAIG, M.D.

Alexander's Dictionary of Weights and Measures.

New Edition. 8vo. Cloth. $3.50.

UNIVERSAL DICTIONARY OF WEIGHTS AND MEASURES, Ancient and Modern, reduced to the standards of the United States of America. By J. H. ALEXANDER.

Elliot's European Light-Houses.

51 Engravings and 21 Wood-cuts. 8vo. Cloth. $5.00.

EUROPEAN LIGHT-HOUSE SYSTEMS. Being a Report of a Tour of Inspection made in 1873. By Major GEORGE H. ELLIOT, U. S. Engineers.

Sweet's Report on Coal.

With Maps. 8vo. Cloth. $3.00.

SPECIAL REPORT ON COAL. By S. H. SWEET.

Colburn's Gas Works of London.

12mo. Boards. 60 cents.

GAS WORKS OF LONDON. By ZERAH COLBURN.

Walker's Screw Propulsion.

8vo. Cloth. 75 cents.

NOTES ON SCREW PROPULSION, its Rise and History. By Capt. W. H WALKER, U. S. Navy.

Pook on Shipbuilding.

8vo. Cloth. Illustrated. $5.00.

METHOD OF PREPARING THE LINES AND DRAUGHTING VESSELS PROPELLED BY SAIL OR STEAM, including a Chapter on Laying-off on the Mould-loft Floor. By SAMUEL M. POOK, Naval Constructor.

Saeltzer's Acoustics.

12mo. Cloth. $2.00.

TREATISE ON ACOUSTICS in connection with Ventilation. By ALEXANDER SAELTZER.

Pickert and Metcalf's Art of Graining.

1 vol. 4to. Tinted Paper. Cloth. $10.00.

THE ART OF GRAINING, with description of Colors and their Application. By CHARLES PICKERT and ABRAHAM METCALF. With 42 tinted plates of the various woods used in interior finishing.

Wanklyn's Milk Analysis.

12mo. Cloth. $1.00.

Milk Analysis. A Practical Treatise on the Examination of Milk, and its Derivatives, Cream, Butter, and Cheese. By J. Alfred Wanklyn, M.R.C.S.

Rice & Johnson's Differential Functions.

Paper, 12 mo. 50 cents.

On a New Method of Obtaining the Differentials of Functions, with especial reference to the Newtonian Conception of Rates or Velocities. By J. Minot Rice, Prof. of Mathematics, U. S. Navy, and W. Woolsey Johnson, Prof. of Mathematics, St. John's College, Annapolis.

Coffin's Navigation.

Fifth Edition. 12mo. Cloth. $3.50.

Navigation and Nautical Astronomy. Prepared for the use of the U. S. Naval Academy. By J. H. C. Coffin, Professor of Astronomy, Navigation and Surveying; with 52 wood-cut illustrations.

Clark's Theoretical Navigation,

8vo. Cloth. $3.00.

Theoretical Navigation and Nautical Astronomy. By Lewis Clark, Lieut.-Commander, U. S. Navy. Illustrated with 41 woodcuts, including the Vernier.

Toner's Dictionary of Elevations.

8vo. Paper, $3.00 Cloth, $3,75.

Dictionary of Elevations and Climatic Register of the United States. Containing, in addition to Elevations, the Latitude, Mean Annual Temperature, and the total Annual Rain Fall of many Localities; with a brief introduction on the Orographic and Physical Peculiarities of North America. By J. M. Toner, M.D.

XIII. A PRACTICAL TREATISE ON THE GASES MET WITH IN COAL MINES. By the late J. J. ATKINSON, Government Inspector of Mines for the County of Durham, England.

XIV. FRICTION OF AIR IN MINES. By J. J. ATKINSON, author of "A Practical Treatise on the Gases met with in Coal Mines."

XV. SKEW ARCHES. By Prof. E. W. HYDE, C.E. Illustrated with numerous engravings and three folded plates.

XVI. A GRAPHIC METHOD FOR SOLVING CERTAIN ALGEBRAIC EQUATIONS. By Prof. GEORGE L. VOSE. With Illustrations.

XVII. WATER AND WATER SUPPLY. By Prof. W. H. CORFIELD, M.A., of the University College, London.

XVIII. SEWERAGE AND SEWAGE UTILIZATION. By Prof. W. H. CORFIELD, M.A., of the University College, London.

XIX. STRENGTH OF BEAMS UNDER TRANSVERSE LOADS. By Prof. W. ALLAN, author of "Theory of Arches." With Illustrations

XX. BRIDGE AND TUNNEL CENTRES. By JOHN B. MCMASTERS, C.E. With Illustrations.

XXI. SAFETY VALVES. By RICHARD H. BUEL, C.E. With Illustrations.

XXII. HIGH MASONRY DAMS. By JOHN B. MCMASTERS, C.E. With Illustrations.

XXIII. THE FATIGUE OF METALS under Repeated Strains, with various Tables of Results of Experiments. From the German of Prof. LUDWIG SPANGENBERG. With a Preface by S. H. SHREVE, A.M. With Illustrations.

XXIV. A PRACTICAL TREATISE ON THE TEETH OF WHEELS, with the theory of the use of Robinson's Odontograph. By S. W. ROBINSON, Prof. of Mechanical Engineering, Illinois Industrial University.

XXV. THEORY AND CALCULATIONS OF CONTINUOUS BRIDGES. By MANSFIELD MERRIMAN, C.E. With Illustrations.

The University Series.

No. 1.—ON THE PHYSICAL BASIS OF LIFE. By Prof. T. H. HUXLEY, LL.D., F.R.S. With an introduction by a Professor in Yale College. 12mo, pp. 36. Paper cover, 25 cents.

No. 2.—THE CORELATION OF VITAL AND PHYSICAL FORCES. By Prof. GEORGE F. BARKER, M.D., of Yale College. 36 pp. Paper covers, 25 cents.

No. 3.—AS REGARDS PROTOPLASM, in relation to Prof. HUXLEY'S Physical Basis of Life. By J. HUTCHINSON STIRLING, F.R.C.S. 72 pp., 25 cents.

No. 4.—ON THE HYPOTHESIS OF EVOLUTION, Physical and Metaphysical. By Prof. EDWARD D. COPE. 12mo, 72 pp. Paper covers, 25 cents.

No. 5.—SCIENTIFIC ADDRESSES:—1. On the Methods and Tendencies of Physical Investigation. 2. On Haze and Dust. 3. On the Scientific Use of the Imagination. By Prof. JOHN TYNDALL, F.R.S. 12mo, 74 pp. Paper covers, 25 cents. Flex. cloth, 50 cents.

No. 6.—NATURAL SELECTION AS APPLIED TO MAN. By ALFRED RUSSELL WALLACE. This pamphlet treats (1) of the Developement of Human Races under the Law of Selection; (2) the Limits of Natural Selection as applied to Man. 54 pp. 25 cents.

No. 7.—SPECTRUM ANALYSIS. Three Lectures by Profs. ROSCOE, HUGGINS and LOCKYER. Finely Illustrated. 88 pp. Paper covers, 25 cents.

No. 8.—THE SUN. A sketch of the present state of scientific opinion as regards this body. By Prof. C. A. YOUNG, Ph. D. of Dartmouth College. 58 pp. Paper covers, 25 cents.

No. 9.—THE EARTH A GREAT MAGNET. By A. M. MAYER, Ph. D., of Stevens' Institute. 72 pp. Paper covers, 25 cents. Flexible cloth, 50 cents.

No. 10.—MYSTERIES OF THE VOICE AND EAR. By Prof. O. N. ROOD, Columbia College, New York. Beautifully Illustrated. 38 pp. Paper covers, 25 cents.